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RUNOFF AND RECHARGE

Improving Water Quality and Groundwater Recharge Through Alternative Drainage Designs

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Metropolitan Area Planning Council
MAPC

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RUNOFF AND RECHARGE:

Improving Water Quality and Groundwater Recharge through Alternative Drainage Designs

Spring, 1984

METROPOLITAN AREA PLANNING COUNCIL

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ABOUT THIS REPORT

This handbook was prepared by the staff of the Metropolitan Area Planning Council under the supervision of its Executive Director. The Metropolitan Area Planning Council is the officially designated regional planning agency for 101 cities and towns in the Boston metropolitan area. The Council offers technical assistance to its member communities in the areas of land use, housing, environmental quality, energy, transportation, and economic development.

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Introduction

PURPOSE OF THIS GUIDEBOOK

Flooding and erosion are familiar stormwater concerns. Agencies, such as the state and county agricultural extension services and the U.S. Soil Conservation Service, provide good advice on designing drainage systems to reduce flooding and erosion impacts. This guidebook, however, while acknowledging that flooding and erosion are legitimate problems, will examine the lesser known groundwater recharge and water quality issues of runoff. Most local officials have been reluctant to require recharge and pollution-control drainage designs because the seriousness of these runoff problems and the technical efficiency and cost effectiveness of treatment methods are often unclear.

This guide is intended for use by local officials, such as conservation commissions, boards of health, public works departments and planning boards. All of these groups are likely to be involved in some aspect of drainage design. For instance, conservation commissions are charged with preventing pollution and flooding through development review under the Wetlands Protection Act (MGL Ch.131, s.40). Planning boards (MGL 41) and boards of health (MGL 111) also review drainage designs to protect property and public safety. The different responsibilities of each separate reviewing agency sometimes results in conflicting prescriptions for a particular site's drainage system. Confusion among the project proponent and town boards may arise. This guide is intended to provide local officials with sufficient information to be able to incorporate recharge and pollution considerations into their drainage planning.

RUNOFF IN THE HYDROLOGIC CYCLE

The hydrologic cycle is the exchange of water between the earth and the atmosphere. Water enters the atmosphere by evaporation from oceans, lakes and rivers, and by transpiration from plant leaves. This vapor rises until it becomes cooled high in the atmosphere. The vapor condenses into droplets, which fall as precipitation.

In a natural, undeveloped setting, some of the precipitation evaporates immediately, some is absorbed into the soil and is drawn up by plant roots, and some percolates deeply into the soil, adding to the groundwater supply. The remaining precipitation ends up as runoff or water that flows overland until it joins an existing stream, lake or sea. Evaporation of these surface waters starts the cycle anew. (See Figure 1.)

Thus, runoff occurs as a natural part of the water cycle. The volume and speed of the runoff flow depends on the storm intensity and land features, such as slope and soil condition. Vegetation slows the velocity of runoff and reduces its volume by storage and root uptake of the water.

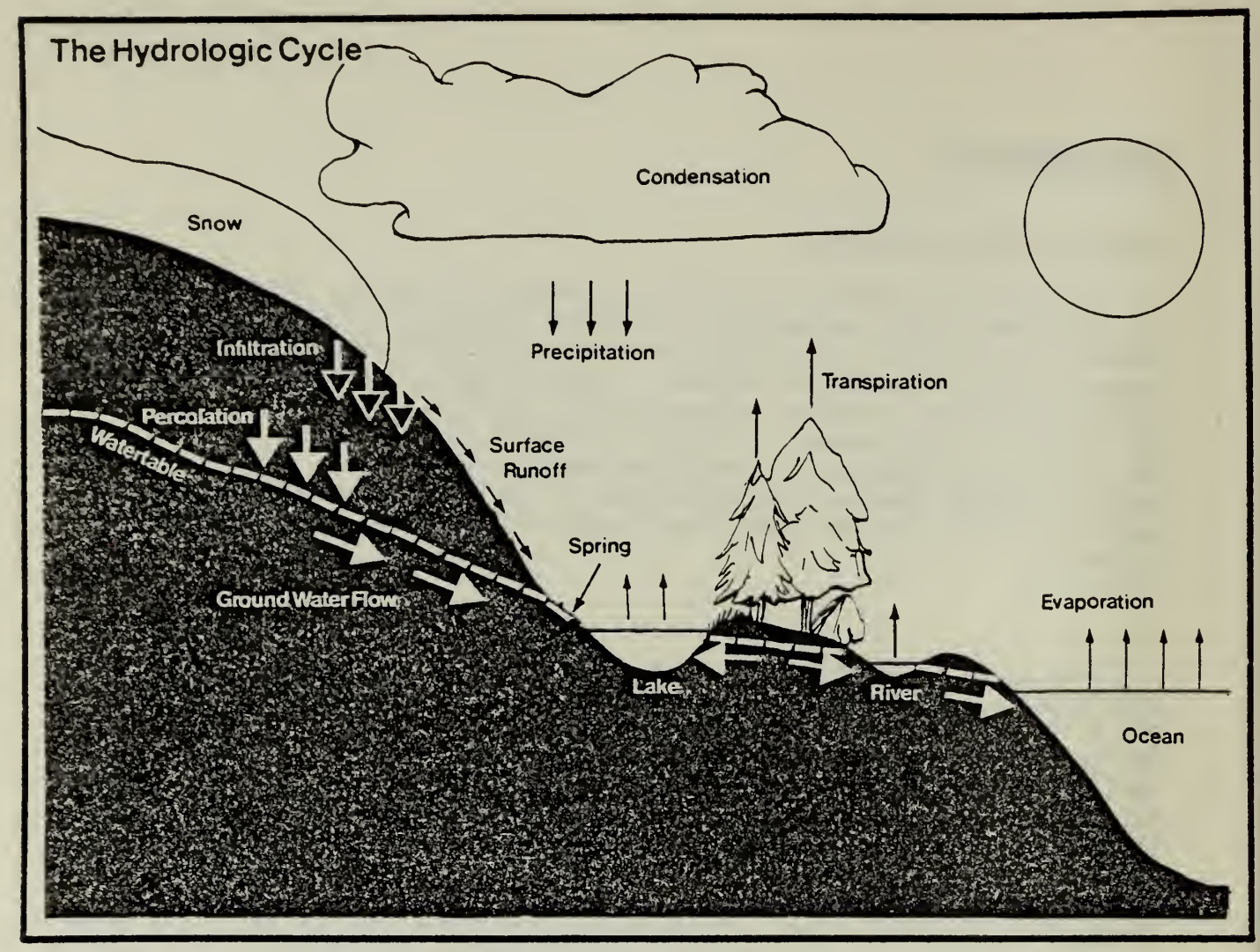


Figure 1. Generalized Hydrologic Cycle. Runoff can form directly from precipitation or as a result of melting snow.

PROBLEMS OF RUNOFF

The hydrologic cycle is altered by the construction of homes, streets, parking lots and other necessities of modern life. Urbanization creates impervious surfaces that reduce infiltration and increase runoff. (See Figure 2.) For example, more than 80 percent of the water that falls on a paved parking lot exits as runoff, compared to a runoff rate of less than 20 percent for grassy areas. (See Table 1.)

Figure 2. Large impervious areas, such as parking lots, increase runoff quantity and decrease runoff quality.

Table 1. Runoff Rates[2]

Type of Surface	Runoff Rate (%)
Roof Surface	75-95
Asphalt Pavements	80-95
Concrete Pavements	70-90
Brick Pavements	70-85
Gravel Roads	35-70
Impervious Soils	40-65
Impervious Soils with Vegetation	
Flat, <2% slope	9-15
Average, 2 to 7% slope	15-22
Steep, >7% slope	22-40
Pervious Soils	5-20
Pervious Soils with Vegetation	
Flat, <2% slope	0-10
Average, 2 to 7% slope	10-15
Steep, >7% slope	15-20

Excess runoff, or stormwater, may cause problems by either flowing too quickly across the land, causing erosion, or by collecting in an inappropriate location, resulting in flooding. To manage these hazards, engineers have designed systems of underground drains and pipes to channel stormwater away from homes and roads. Channelling runoff into pipes usually increases stormwater velocity. Most drains empty into streams where this increased velocity may accelerate streambank erosion. Erosion reduces property values, strips the land of valuable topsoil, changes drainage patterns and clogs waterways with sediment. Runoff solutions have traditionally been designed with flood and erosion control in mind because these two consequences of stormwater have such a visible impact on the safety and convenience of people's lives.

In recent years, however, two other important runoff issues have emerged. The first is also related to runoff quantity. Impervious surfaces, such as roofs, roads and parking lots, prevent stormwater from infiltrating the soil. Without this seepage, precipitation cannot recharge the aquifer, which means the groundwater found in the soil will not be replenished. Runoff piped directly into surface water also precludes the chance to replenish aquifers significantly. If groundwater is important to an area as a water supply for drinking or other uses, drainage systems should be designed to reduce runoff and increase recharge.

A second runoff problem recognized only recently is stormwater quality. Stormwater washes contaminants, including oil, metals, salts and wastes into the waters that receive the runoff.3 Characteristics of the storm, contaminants, drainage system and receiving waters all have to be weighed to determine if runoff is degrading water quality in an area. All runoff is tainted to some degree, but not all runoff causes pollution problems.

Flooding, erosion, loss of groundwater recharge and contamination are recognized problems of stormwater runoff. There is no single solution to cure all four problems simultaneously. Some drainage designs may handle one or two aspects, but may exacerbate others. The dominant concerns at a site must be determined before a choice can be made from the wide variety of available drainage techniques.

Runoff Contamination

RUNOFF CONTAMINANTS AND THEIR EFFECTS

Rainfall is the original street cleaner. Stormwater running along a paved surface carries loose materials away with the flow. After the storm, the streets are cleansed of various debris. To estimate the water quality of runoff, we must examine the nature of the debris.

Many studies have been conducted on the amounts and sources of contaminants in stormwater. The type of contamination varies according to region (road salts are used less in the South than in the North) and land use (highway runoff contains more heavy metals than residential street runoff). In general, urban runoff is likely to be more contaminated than sanitary sewage flows.4

It is also agreed that street dust and dirt are the primary contributors to runoff pollution and that the most toxic contaminants are found in the smallest dust-sized particles.5 For example, half of the nutrients (nitrogen and phosphorus compounds) and heavy metal contaminants are found in fine silt particles swept away by runoff.6 This correlation between toxic components and tiny particles is important because silts are usually the hardest to remove from runoff.

Potential pollutants in runoff may be classified into several broad groups: suspended solids, organic wastes/nutrients, heavy metals, hydrocarbons and salts. Each type of contaminant has a different water quality impact and drainage techniques to control one type of contaminant may not be as effective for another. The relative amounts, sources and effects of each type of runoff contaminant are given below:

Suspended Solids

These solids are mostly inorganic, such as soil particles. They are the most visible contaminants in stormwater because, by definition, they do not dissolve. They also contribute the most contaminants by weight. The most recent research by EPA's Nationwide Urban Runoff Program suggests that concentrations of solids in runoff are lower than previous studies indicated.7 Solids are important not only for their own physical impact on receiving waters, but also because dirt serves as a carrier, absorbing other pollutants, such as metals and pesticides.

Sources of suspended solids in runoff include stockpiles, land grading, excavation, demolition, construction, wind erosion - and many other activities that leave debris and soil exposed and vulnerable to erosion by stormwater. Other sources include wind-driven fallout of dust particles, deposition by vehicles, road sanding in winter and abrasion of road surfaces.

Solids can cause problems while they are still suspended or as they settle out. Suspension effects are more prevalent in river systems, while settling problems predominate in lakes or standing waters. Turbidity is the clouding effect caused by solid particles churned up in the water. Turbid water affects plants and animals. In an extreme situation, fish gills can be clogged with dirt and feeding may be impaired. By increasing the opacity of the water, turbidity reduces the light penetration inhibiting photosynthesis needed for plant growth. Turbidity can also interfere with recreation, such as swimming and aesthetic enjoyment. Cloudy waters look polluted.

When suspended solids settle, bottom-dwelling (benthic) creatures, such as shellfish and seaworms may be buried and their habitat destroyed. The deposition of sediment may also prevent respiration by lowering dissolved oxygen levels near the bottom. The bottom configuration may be altered by the settling of solids and water currrent speeds and patterns could be disrupted. Navigation can be impeded if channels become clogged and costly dredging is often required.

Suspended solids have little effect on groundwater if runoff is emptied onto the land surface unless large quantities of fine-grained particles in runoff clog the permeability of the soil. But suspended solids carry other types of pollutants, such as pesticides, which could eventually leach into the ground.

Organic Wastes

These components of runoff are animal and vegetable wastes. Most prominent in this class is sewage (primarily animal droppings), fertilizers, leaf litter, grass clippings, street litter and garbage collection remnants. All of these wastes contain nitrogen and phosphorus compounds. Nitrogen is also released, surprisingly, by tire wear on roads. Car wash detergents also contribute phosphorus.

These nitrogen and phosphorus compounds are called nutrients because they upset environmental balance by overstimulating growth of vegetation. While all organisms need nurients to grow, these compounds are problems in excess. Even small amounts of nutrients can cause algal blooms. (The U.S. Environmental Protection Agency recommends levels less than 0.3 parts per million (ppm) for

nitrogen and 0.0015 ppm for phosphates in waters to prevent blooms.)8 Algal blooms occur when the growth of algae is so rapid that the water acquires a greenish tint or a floating scum of vegetation. Mats of algae can form near the shore, preventing swimming and navigation.

When the algae die and sink to the bottom, they consume large amounts of oxygen as they decompose. Oxygen is also depleted during decay of other wastes in the water. Dissolved oxygen is crucical to aquatic life. (Massachusetts officials use a standard of 6 ppm for cold water fisheries).9 Even if dissolved oxygen is not depleted enough to kill fish, species may exhibit signs of stress, such as abnormal feeding and breeding behavior. This process of nutrient input, rapid vegetative growth, algae decomposition and lower oxygen levels is known as eutrophication or the "choking" of a water body until it fills in weeds and becomes a swamp or marsh. While this process is natural, excessive nutrients introduced by runoff artifically accelerates the eutrophication rate.

The amount of nutrients found in runoff can be substantial. The Metropolitan Area Planning Council determined in a 1977 report that nutrients in stormwater consistently exceeded toxic limits for pond life in the greater Boston area.10 In 1982 the Massachusetts Department of Environmental Quality Engineering identified phosphorus from runoff as a major polllutant in Worcester's Lake Quinsigamond.11

Nutrients are also a concern in groundwater. Nitrates are nitrogenous compounds that can travel great distances in solution through the soil and may contaminate drinking water. (The Massachusetts drinking water standards for nitrates is 10 ppm.) Methemoglobinemia, or the "blue-baby" syndrome, has been attributed to nitrates in drinking water and nitrates are carcinogens.12

While all organic wastes release nutrients, sewage also contains harmful bacteria and viruses. The effect of bacteria are usually localized and short-lived, but recent research has shown that viruses are more persistent and can be transported great distances. Concern is presently being expressed over the infiltration of viruses into groundwater.13

Heavy Metals

Heavy metals contribute most of the toxicity of runoff. These elements are found often enough and in large enough quantities to represent the major threat to water quality. Large amounts of lead and zinc are consistently found in runoff.14 Other toxic heavy metals in runoff are copper, chromium, arsenic and mercury.

Most sources of heavy metals in runoff are related to transportation activities, as Table 2 illustrates. Metals are also present in soils in small but detectable background concentrations.

Table 2. Sources of Heavy Metals in Runoff[15]

Element	Major Sources	Minor Sources
Lead	fuel combustion motor oil	tire wear fallout roadpaint
Zinc	tire wear motor oil	lane-stripe paint
Copper	brake linings	engine plating and parts plumbing corrosion pesticides
Mercury	fallout	reaction with road salt
Chromium	engine plating and parts	lane-stripe paint brake lining fallout asphalt
Cadmium	tire wear found in zinc	
Iron	vehicle rust	
Arsenic	herbicides	fuel combustion detergent
Nickel	engine plating and parts asphalt	brake linings fuel combustion

Heavy metals in runoff cause concern due to their high toxicity and frequent occurrence. In large quantities, metals can kill fish. Chronic effects occur over a long time as metals accummulate in a water body's sediment and in the tissue of aquatic organisms. Species diversity may shift depending on different levels of tolerance. Metals also cause mutations and alter reproduction.16

Different metals have different toxicities. Copper and zinc are not as toxic to humans as they are to smaller species.17 Lead and most metals are of more concern to surface waters than ground water. Soils can trap and immobililze up to two-thirds of the metals in stormwater.18 Metals can also be removed by root uptake of plants.

Hydrocarbons

In general, hydrocarbons include a wide range of organic (carbon-based) chemicals. Two types of hydrocarbons contaminating stormwater are oils and chlorinated hydrocarbons (e.g., pesticides and solvents).

Oil and grease are the major hydrocarbons found on streets.19 Petroleum leaks and spills from vehicles are very common. Gasoline, diesel fuel, crankcase oil and lubricants all taint runoff. Most petroleum products also contain significant concentrations of toxic materials, such as heavy metals (e.g., lead and zinc), and gasoline additives (e.g., benzene and toluene).

Another source of oil in runoff is the road surface itself. Asphalt's cementing is made of crude oil remnants. Asphalt can be loosened by vehicular traffic abrasion or weakened by fuel spills. Worn asphalt particles are the main contributor to street dust.20

Oil-like substances include coal tar and creosote, which are often used to protect telephone poles and other timber products from decay. These coatings frequently contain toxic phenols that can leach into stormwater.21

Chlorinated hydrocarbons range from polychlorinated biphenyls (PCBs) to organic solvents to pesticides. PCBs, whose manufacture in the U.S. was outlawed in 1977 when their toxicity became apparent, are found in plastics and certain light fixtures, but are primarily used as insulating fluids circulated through electrical transformers. These transformers, found atop telephone poles, sometimes leak. PCBs are consistently found in runoff around the nation.22

Pesticides and solvents comprise the remaining types of chlorinated hydrocarbons in runoff. These compounds are usually found in low concentrations, but their toxicity and persistence cause concern. Commonly identified pesticides are DDT, dieldrin, and lindane. In addition, grease-cleaning solvents, such as trichloroethene, used in auto repair and light industry, find their way into stormwater primarily through careless disposal practices.

Hydrocarbons exhibit many of the same traits of metals in receiving waters. Oil slicks can cause immediate fish kills or settle to the bottom and be released into the water over a long time period. Chlorinated hydrocarbons can be especially persistent. Hydrocarbons can lower oxygen levels, create a film on the water's surface, kill or mutate organisms, contribute heavy metals and become concentrated in the food chain. Lightweight fractions of hydrocarbons, such as gasoline, are more toxic, but less persistent than thick residual oils. Groundwater is very susceptible to pollution by the lightweight fractions, which can infiltrate into the ground in liquid form and even farther in gaseous form through soils.23 Hydrocarbons in minute levels in drinking water can be tasted or smelled.

Salts

The use of deicing salt on highways is mainly responsible for high concentrations of chlorides, sodium and calcium in runoff. Runoff from uncovered road salt stockpiles is another source, though great progress has been made in covering these piles with weatherproof sheds.24

Many states use road salts containing heavy metal impurities, such as lead and zinc, which are used as fillers.25 Massachusetts, however, uses road salts without these toxic fillers.26 Sodium ferrocyanide is used as an anti-caking agent in the salt. When this compound decomposes, it can release cyanide - an extremely toxic chemical.27

Every organism needs a certain amount of salt to survive, but excess salt is dangerous to people with heart diseases and hypertension. Salt runoff near roadways can "burn" vegetation and kill it. Salt also reduces soil fertility. In water bodies, high salt levels can kill fish and affect the reproduction and longevity of all freshwater species.28 New research suggests salt can stimulate algae growth and hinder the seasonal mixing of water layers; both of these effects contribute to eutrophication.29 Water used for irrigation must also be monitored for salinity to prevent crop damage.

Salt in runoff does not pose a significant threat to marine life because most salt water species, particularly nearshore, have adapted to salinity fluctuations. (Ironically, some crabs and oysters, which are sensitive to salinity changes, may be harmed by the introduction of too much runoff without salt in it.) Because of its high solubility, however, salt poses the greatest danger to groundwater. While using runoff to replenish aquifers is a laudable practice, this technique should not be employed using salt-laden stormwater from roads that are salted in winter.

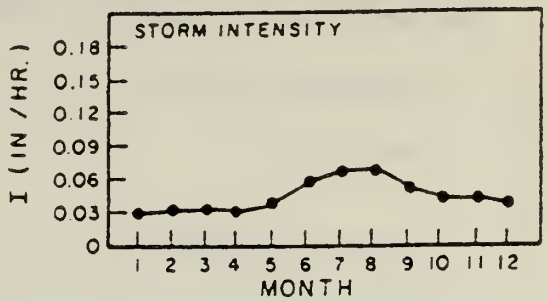
ENVIRONMENTAL FACTORS INFLUENCING EFFECTS OF RUNOFF

Climate, soils, land use, topography and existing drainage systems will all affect the risk to water quality posed by stormwater in an area. While it is important to analyze each site individually, some general statements can be made for most sites in eastern Massachusetts compared to the rest of the United States.

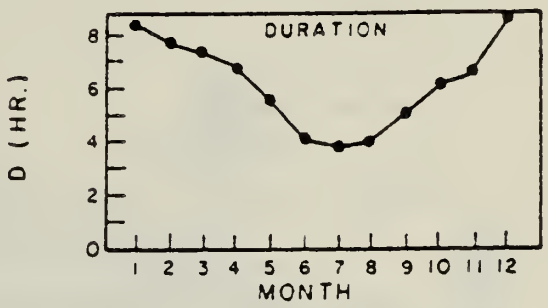
The Boston area's climate is characterized by low-intensity storms that occur frequently and produce large volumes of precipitation over a long time. (Monthly averages for Boston area shown in Figure 3.) How does this wet climate affect runoff? Low-intensity storms, measured in inches per hour, have less ability to wash off pollutants than intense thunderstorms. Boston has the longest storms of anywhere in the nation (averaging more than six hours), which tends to reduce the so-called "first-flush" effect of pollutants. The first flush effect describes the tendency for accummulated contaminants to be concentrated at higher levels in stormwater generated early during the storm.30 The large volume of precipitation in an average storm means runoff volumes will also be great, adding a large dilution factor to the contaminants in the runoff. (See Appendix A for formulae to estimate runoff quantities.) Finally, because storms occur frequently near Boston, there is less time for pollutant loads to build up on the land surface after the preceding storm.

In comparison with most of the United States,
the Boston area experiences storms that are...

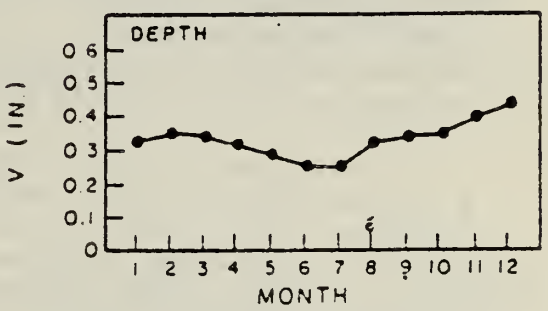
...of LOW-INTENSITY...



...but LONG-LASTING...



...and that produce LARGE VOLUMES
of precipitation...



...and occur FREQUENTLY.

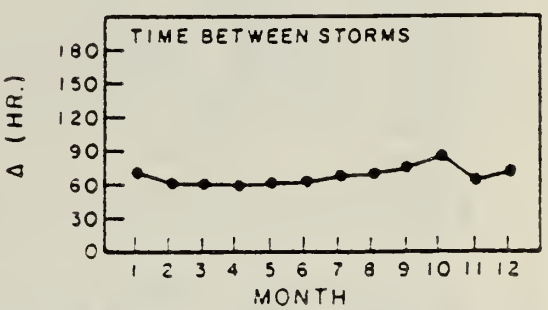


Figure 3. Boston Rainfall Averages, 1948-1973.
Source: U.S. Environmental Protection Agency, A Statistical Method for the Assessment of Urban Stormwater, Washington, D.C., 1979, p. 5-11.

The combination of these factors alone would seem to imply that Massachusetts should have fewer problems with stormwater quality than other places in the country. Nevertheless, stormwater sampling conducted by the Metropolitan Area Planning Council (MAPC) in 1977 found that runoff quality was poor throughout the Boston area. Specifically, the following contaminants were characterized in runoff by MAPC:

Suspended solids	- of "primary importance" due to volume
Nutrients	- "exceed aquatic life limits almost all of the time"
Coliform bacteria	- always above the levels allowed for swimming and shellfish
Salts	- "predominantly high", particularly in cities
Hydrocarbons	- "high compared to other contaminant sources"
Heavy Metals	- "lead and zinc found universally in storm drains"

While these findings describe the quality of the stormwater and not the receiving water, they indicate that runoff can be severely polluted in the greater Boston region.31 The buffering effect that Boston's wet climate should have on runoff is not supported by sampling analysis. So other factors influencing runoff quality must be considered.

It is agreed that developed land has impervious surfaces (roofs, roads, sidewalks) that increase runoff volume, but it is still unclear how different land uses affect runoff quality. In theory, residential areas should contribute different types and loads of contaminants than industrial areas, which, in turn, should produce runoff with different contaminants than those found on highways. In fact, however, nutrients in runoff, for example, are found in similar concentrations in both subdivisions and downtown business zones. Highway runoff characteristics are most like those of business areas - particularly high in heavy metals - although salt is more concentrated in highway stormwater.32 Industrial areas contribute high loads of suspended solids.33 In general, developed land experiences higher runoff volume and higher pollutant loads than rural land. The fact that metropolitan Boston is a highly urbanized area may account for the poor quality of runoff in the region.

Existing drainage systems can also influence runoff quality. "Closed" drainage refers to the traditional method of collecting stormwater by gutters, curbs, inlets or catch basins and connecting pipes. Because the Boston area is a long-established urban center, these closed systems predominate in most cities and towns. Collecting the runoff in this manner concentrates stormwater contaminants. Conversely, "open" drainage, which uses overland flow through natural channels and swales, disperses contaminants in lower concentrations over a wider area. Concentrating the pollutants by drains and pipes is not inherently harmful; much depends on where the stormwater is deposited.

Unfortunately, most pipes empty directly into natural watercourses as shown in Figure 4. There are three problems with this method, First, it delivers pollutants from a wide drainage area into one small site. Second, it squanders the opportunity to treat contaminants already collected in a centralized system. Third, as mentioned previously, it prevents aquifer recharge.

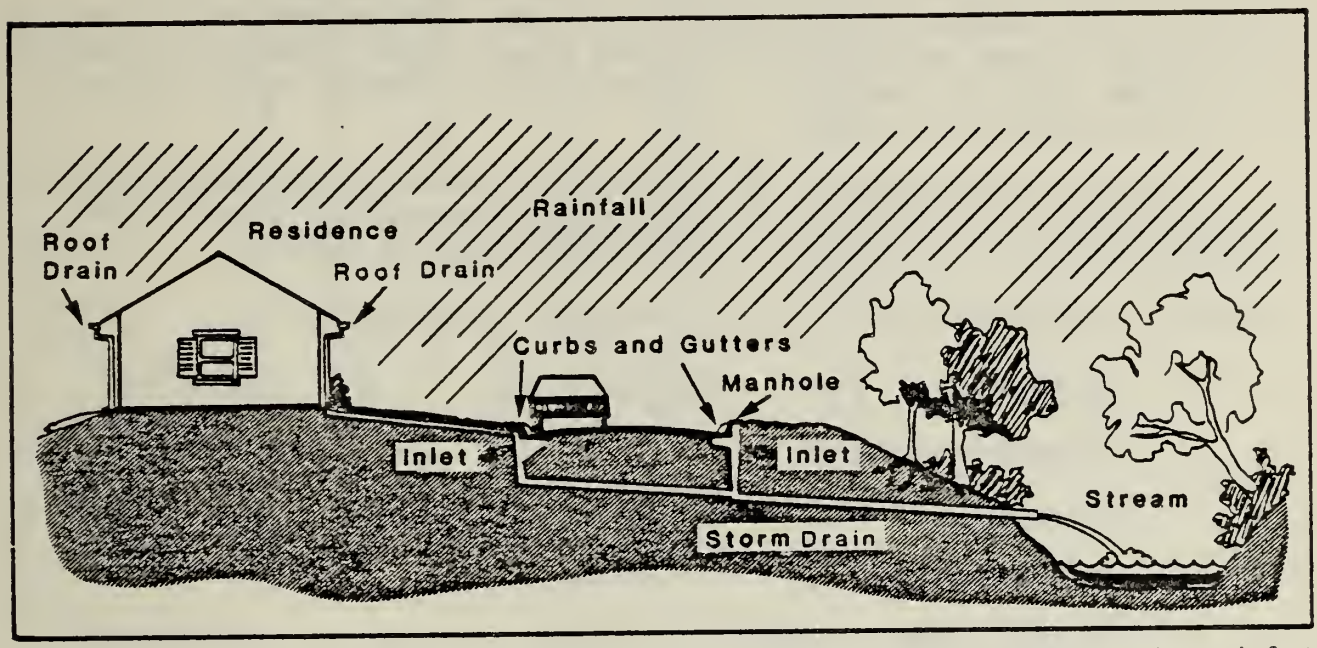


Figure 4. Typical Closed Drainage System. (Catch basins often replace inlets.) Source: Southwestern Illinois Metropolitan and Regional Planning Commission.

In some cities, including parts of Boston, storm drains lead into sanitary sewer systems. These combined sewers then lead to a treatment plant. Problems with combined sewers include the inability of the plant to handle the extra volume during a storm. Consequently, untreated runoff and sewage may bypass the treatment process entirely. In the Boston area served by the Metropolitan District Commission, these untreated overflows are sometimes shunted directly into Boston Harbor.

Closed drainage is already widely extant and will probably continue to be preferred by engineers to minimize on-site flooding and erosion. While flooding and erosion can be controlled by directing runoff into drains and pipes, stormwater quality and loss of groundwater recharge can be handled when the flow exits the pipe. Instead of regarding pipe flow as a concentrated source of washed-off land contaminants that degrade receiving waters, drains can be regarded as a beneficial collector because they present a good opportunity to store and treat runoff. The concentrated contaminants in storm drains make some treatment methods more cost-effective if situated at the end of the pipe. Only if the engineers take advantage of this storage/treatment option can closed drainage be viewed in a beneficial light. Otherwise, contaminants in storm drains will continue to menace receiving waters.

The soils and topography of the greater Boston area vary considerably, but they also influence runoff. In general, the topography can be classified as coastal plain, characterized by few rolling hills and numerous low spots. This low relief precludes development of the erosive force frequently generated by storms in mountainous areas. Soil types range from densely-packed clays to sand and gravel. Sand and other coarse-grained soils allow rapid infiltration of precipitation into the ground and so reduce runoff volumes. Rapid infiltration, however, may also readily introduce contaminants into the aquifer. For example, when dissolved salt seeps through dense soils, most of the sodium becomes entrapped in the upper layers, while the chlorides continue to migrate into the groundwater. In sandy soils, however, both sodium and chloride penetrate the aquifer.34

Finally, consideration of the quality of receiving waters must be made. In Massachusetts, the background levels of naturally-occurring chemicals in surface waters is low compared to the United States as a whole.

Table 3. Background Levels of Surface Water Constituents35

Constituent	E. Mass. Level	U.S. Range
Suspended solids	5 ppm	5-100 ppm
Nitrates	.05 ppm	.05-.50 ppm
Phosphorus	.02 ppm	.02-.20 ppm
Oxygen-demanding wastes	1 ppm	.5-3 ppm
Cloriform	100 count	100-2000 count
Chlorides	2 ppm	1-10 ppm
Heavy Metals	.2 ppm	.2-1 ppm
pH	6.5	6-8
Hardness ($CaCO_3$)	10 ppm	10-200 ppm

ppm = parts per million

Some may look at the background levels for Massachusetts and claim that because the values are low, the surface waters can sustain greater loadings of pollutants before water quality criteria are exceeded. It is more likely, however, that aquatic life has flourished because of the relatively unpolluted waters in ponds and streams and so would be more sensitive to increased contamination.

Two features of Table 3 should be noted. Waters in Massachusetts have an average natural pH level of 6.5, which is slightly acidic. These waters have become even more acidic in recent decades due to the acid rain phenomenon. Massachusetts waters are particularly vulnerable to acid rain due to the natural scarcity of limestone ($CaCO_3$) deposits that tend to buffer acidic waters.

Table 4. Factors Influencing Runoff Quality

Generally, runoff contamination will be more severe:

- after a long dry spell broken by an intense thunderstorm,
- in areas of mixed land use and fine-grained soils,
- on steep land,
- with old asphalt roads in poor condition used by heavy traffic,
- served by a closed drainage system, discharging untreated into a small stream or a wetland remote from a public water supply.

A site will experience a greater risk of contamination by storm runoff when more of these factors are present.

Generally, runoff contamination will be less severe:

- during frequently-occurring, low intensity storms,
- in undeveloped areas with sandy or humus soils,
- on flat land,
- with new concrete roads in good condition used by light traffic,
- served by open drainage flowing overland into pond in an area used as a public water supply.

A site will experience less risk of contamination by storm runoff when more of these factors are present.

The fact that surface waters are becoming increasingly acidic in Massachusetts has drainage design implications. As mentioned previously, heavy metals are a major component in runoff contaminants due to their high toxicity and frequent occurrence. Acidic water tends to release metals from sediments and dissolves more metals than neutral waters.36 Thus, acid rain is a threat not only because of lowered pH levels, but also because it increases the levels of other contaminants.

Table 4 provides a brief summary of factors influencing the severity of runoff problems in a given area.

Runoff Control, Treatment and Recharge Methods

Traditional drainage designs have already been discussed: water flows along gutters, drops into catch basins, moves through storm-drain pipes and empties directly into surface waters or combines with the sanitary sewer system. Flooding and erosion concerns may be alleviated by this system, but opportunities to clean stormwater and discharge it to the ground are usually overlooked.

Modifications of this closed drainage system exist. Some assist in removing contaminants. Others promote stormwater infiltration to groundwater. Some are expensive; others are not. Some require large areas, which may be impractical in urban areas, while other methods have small space requirements. Complex technology is not required for many alternatives. With sufficient information on the characteristc of each drainage design, appropriate methods can be matched with the specific pollution or recharge problem at any given site.

Stormwater solutions can be grouped in four classes. First, there are methods to reduce pollutant buildup so when it rains there will be fewer contaminants available to runoff. These methods are called pollutant source controls or "housekeeping." The second method is runoff storage. Storage without treatment may not remove pollutants, but it does reduce the peak volumes and velocities of runoff that combine to form the "first flush" effect that shocks receiving waters with contaminants. Third, recharge options will be considered. Most methods to replenish aquifers with stormwater rely on open, natural drainage, but closed drainage can be utilized too. Finally, treatment procedures are available to remove pollutants from stormwater in closed drainage systems.

In order to compare the suitability of each method for a specific site, various features of each drainage design will be considered. These features include:

- primary function
- utility for other runoff problems
- applicable conditions

- space requirements
- cost
- efficiency
- utility for spill control
- maintenance problems
- examples of applications (by town, if available)

CONTAMINANT SOURCE CONTROLS

Street Sweeping

Street sweeping is a traditional practice of local public works departments. A sweeper vehicle is equipped with stiff-bristled brooms rotating to dislodge street litter and dirt. A conveyor belt moves the waste from the brooms to a collection hopper. Originally, street sweeping was conducted solely to remove litter for aesthetic reasons. As runoff quality considerations emerged in the 1960's, street sweepers were also thought to provide water quality benefits by removing contaminants from city streets.

Initial research found that most contaminants were concentrated within a few feet of the curb - the normal operating areas for the broom sweepters. But further research indicated that street sweeping only removed half of the dirt in its path and most of the dirt particles removed were large. This research coincided with the finding that most of the important contaminants, including heavy metals and nutrients, were associated with the "fines" or finest-sized particles, which remained on the pavement.

Most current research, sponsored by EPA, is concluding that broom sweepters have little or no impact on street contaminants. Some studies, in fact, have shown that brushes may increase contaminants by abrading pavements and breaking larger solids into the more threatening fines.37

The alternative to conventional sweeping, though, is vacuum sweeping. With a vacuum attachment on a broom sweeper, more that 90 percent of the solids, including the fines, metals and nutrients, can be removed. The equipment is slightly more expensive, but it requires no new operating procedures.

Site conditions influence sweeper efficiency. Highway sweeping is rarely practiced due to the slow operating speeds of the sweeper, traffic and frequent lack of curbing to concentrate litter. City street sweeping can be hindered by parked cars along the curb. In Massachusetts, the short intervals between storms means less time for pollutants to build up on road surfaces, which makes street sweeping less cost-effective than in more arid parts of the country.

Nevertheless, street sweeping is cost-effective compared to stormwater treatment methods. To remove one ton of pollutants from stormwater by road sweeping costs half as much as removing the same load in a sewage treatment plant. Recent estimates place sweeping costs at $6-$23 per mile of curb.

Catch Basin Cleaning

A catch basin is a small settling chamber placed in a storm drain. Catch basins were originally installed when roads were unpaved and runoff would carry enormous quantities of dirt into drains. The basin retains heavy debris that might otherwise clog the pipes. (See Figure 5.) Ironically, the two million catch basins in the United States are suspected of increasing, not reducing, the amount of contamination in stormwater due to lack of regular maintenance.38 During a rainstorm, the flow entering the catch basin churns up the old sump wastes and resuspends them. The turbid stormwater can be more contaminated when it exits the basin into the pipe than when it enters the basin from the street.

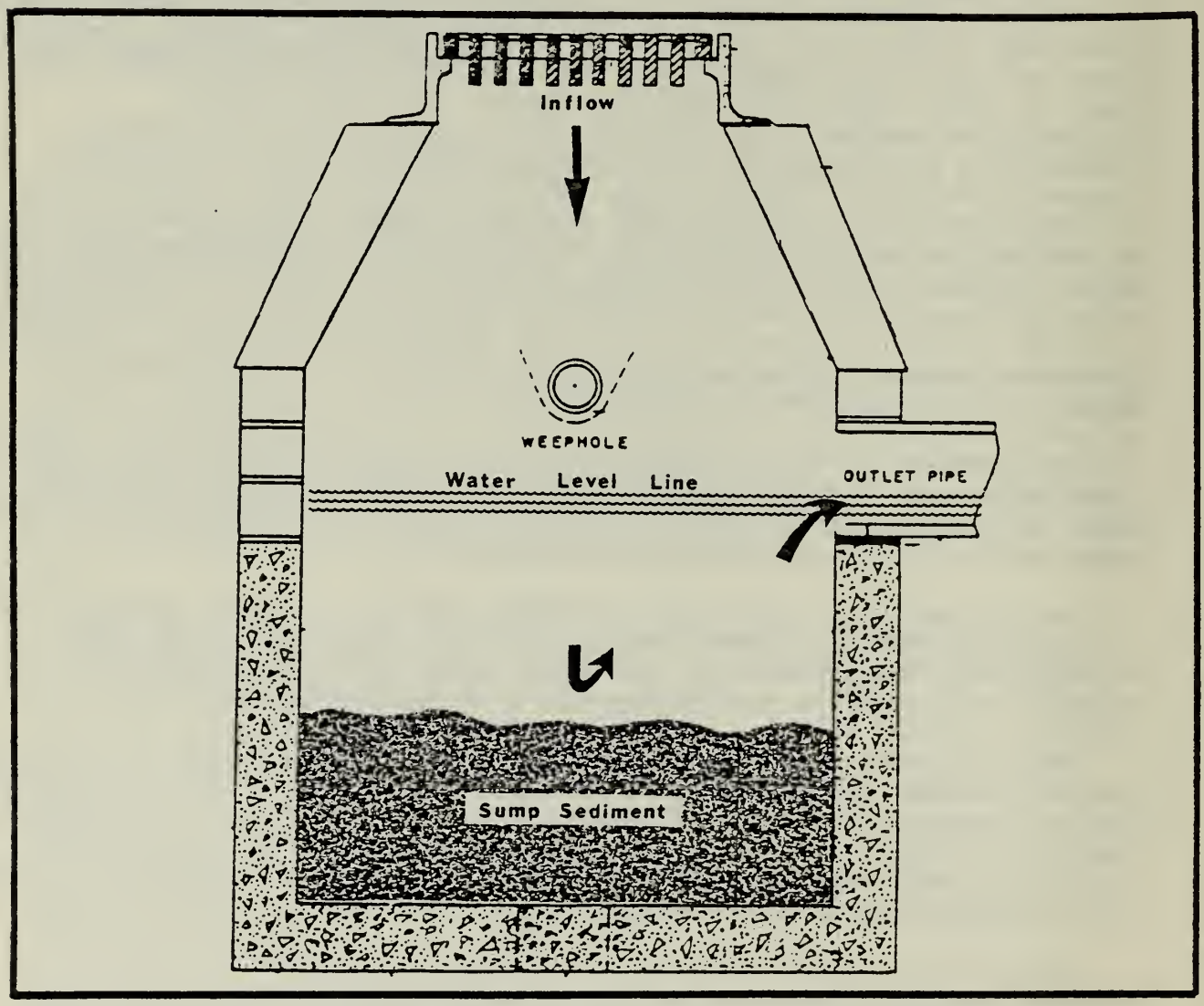


Figure 5. Typical Catch Basin. (Compare with Figures 19-23.)
Source: adapted from Massachusetts Department of Public Works

Because catch basins are often ineffective and most roads are paved today, several studies have recommended replacing catch basins with inlets without sumps. San Francisco has embarked on such a program and has found cash savings due to less frequent cleanings.39 Yet catch basins continue to be installed elsewhere because it has been common practice.

Catch basins can be cleaned manually or mechanically. They can be dredged with buckets or vacuumed. A large vacuum truck, called an eductor, is equipped with a jet hose to loosen the sump sediment and vacuum it up into the truck. Similarly, a vacuum street cleaner can be used for cleaning catch basins. Cleaning costs range from $6-$10 per basin.

Today most sumps are cleaned only once per year, but twenty-five years ago towns cleaned catch basins about twice each year. This reduction in cleaning frequency may have adverse effects on water quality. Sump cleaning should be conducted more frequently for drains leading to sensitive water areas. An advantage of catch basin cleaning in addition to its low cost is that it is a traditional practice with familiar technology. Regular schedules can be established.

Other Source Controls

As with most forms of pollution, preventing stormwater contamination is easier and more effective than treating it. Prevention is particularly important for dissolved pollutants, such as nutrients and salts, which are very difficult to treat. Regulations limiting the amount of fertilizers and road salt applied in a vulnerable drainage area can help. Many towns have established "Salt-Free Zones" to prevent road salting near water supplies. (See Figure 6.)

Public education can encourage people to properly dispose of used motor oil. Litter laws can reduce pollutants on streets. Erosion control, such as staked hay bales to trap sediment on slopes, can reduce solids loading at construction sites. These programs can be as broad-based or site-specific as needed. Enforcement is the key to effectiveness.

STORAGE

The primary purpose of storing runoff is to reduce the volume and velocity of stormwater to aid flood and erosion control. Reducing or delaying the peak flow of runoff can also mitigate the first flush effect, thereby benefitting water quality as well. In this section, storage designs that rely on impervious structures will be discussed; storage by infiltration will be reviewed in the following section.

Storage is a well documented cost-effective method for reducing some runoff problems. It is particularly useful in combined sewer systems, which otherwise would overflow with untreated wastewater. Storage is simple in design and operation. It can be located aboveground, if land is available, or underground, and extra capacity can easily be added to storage areas.

Figure 6. Posted No-Salt Zone, (Duxbury, Mass.) Signs can alert motorists to exercise caution on roads where deicing salt is prohibited by local regulation to protect nearby wellfields and water supplies.

Roof Ponding

People tend to forget that a roof is an imperious surface. Drainage designers can take advantage of this impermeability by using the roof to hold stormwater. Storage is accomplished by bounding flat rooftops with raised parapet walls. A detention ring is used to drain the roof slowly through a constricted downspout. (See Figure 7.) Overflow is provided when the height of the detention ring (typically four inches) is exceeded.

The benefits of roof ponding other than storage include its cooling effect on the building, which can be maximized by circulation. Roof water can also be used in case of fire.

The most obvious problem with roof ponding is the higher structural loads imposed on the building by the water's weight. Most often this concern and leakage problems can be solved by proper design. The detention ring may need maintenance if it clogs, but most flat roofs need inspection and minor maintenance anyway. Freezing may occur in the winter, which may exert pressure sideways due to expansion, but the detention ring can be removed if necessary. On large roofs waves may form, but baffles can break the energy. Obviously, roofs must be flat for ponding. Most industrial plants, office buildings and shopping centers are flat-topped and it is these developed areas that most need stormwater storage.

Parking Lot Ponding

Because there are no structural limits, impervious parking lots have a greater potential for reducing runoff volume and velocity than do rooftops. Lots need not be perfectly level; in fact, the pavement should slope slightly towards a remote area of the parking area so ponding can occur without inconveniencing motorists too frequently. Runoff can flow slowly through small grates into a closed drainage system. (See Figure 8.)

Parking lot ponding is inexpensive because it is easy to design and maintain. Access is conveniently provided for cleaning debris from the depression. The pond is usually accepted by the lot's users as long as it does not block traffic flow and eventually empties.

Where storage depressions are impractical, runoff can be delayed by using a coarse-textured pavement, such as pea stone in binder. The coarse texture will disrupt the momentum of stormwater sheet flow across a smooth lot. Some storage can be achieved within the ripples.

Parking lot ponding also provides an opportunity for oil and hazardous materials spills to be contained on the site. The drain grate could be temporarily replaced by a solid, impervious plate so a spill stays within parking lot confines.

When considering parking lot ponding as a drainage option, it should be recognized that stormwater can become heated to 90^{o} on asphalt on a summer afternoon. Hot runoff can harm fish in streams, particularly sensitive species, such as trout.

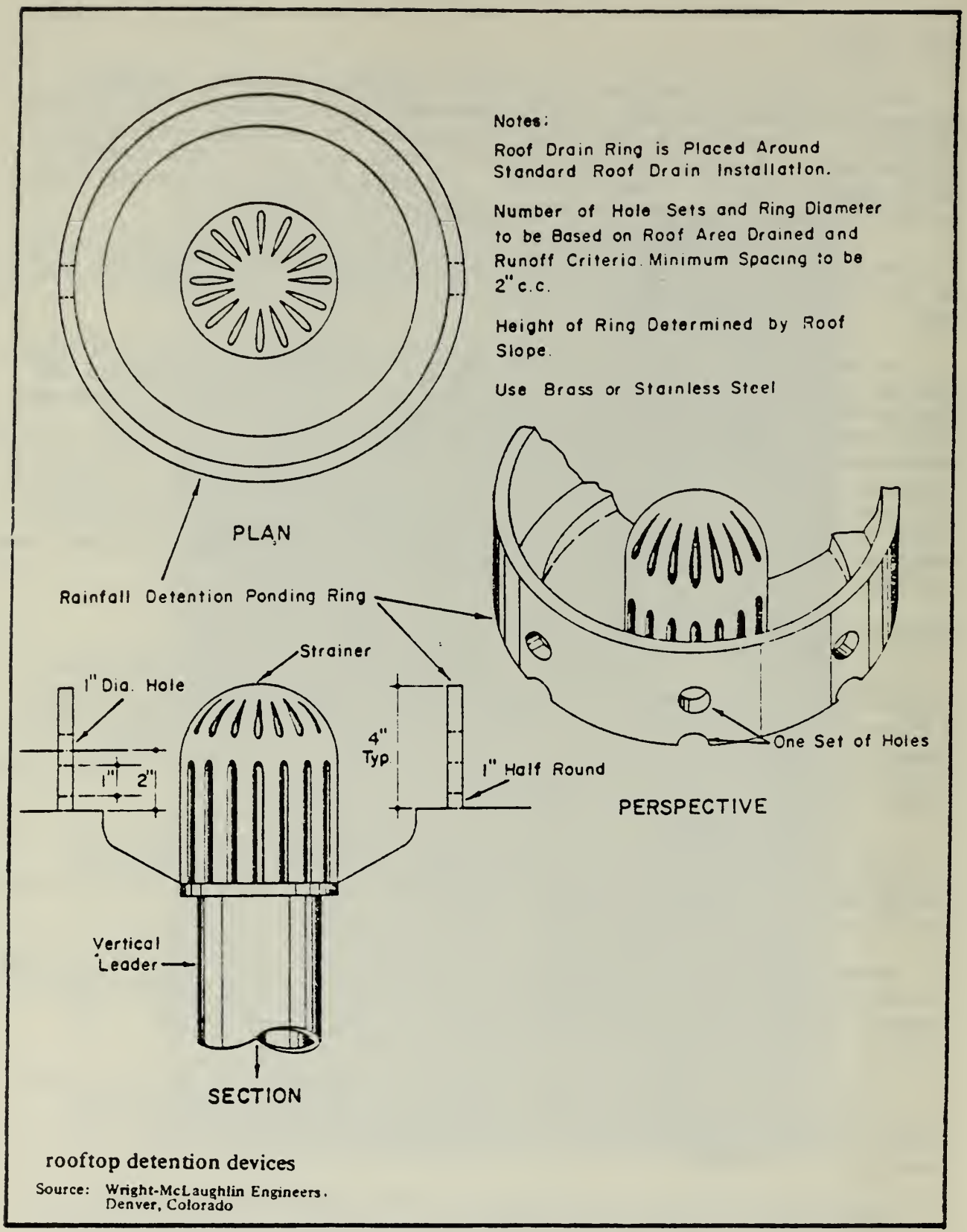

Notes:
Roof Drain Ring is Placed Around Standard Roof Drain Installation.
Number of Hole Sets and Ring Diameter to be Based on Roof Area Drained and Runoff Criteria. Minimum Spacing to be 2" c.c.
Height of Ring Determined by Roof Slope.
Use Brass or Stainless Steel
PLAN
Rainfall Detention Ponding Ring
Strainer
1" Dia. Hole
1"
2"
4" Typ
1" Half Round
One Set of Holes
PERSPECTIVE
Vertical Leader
SECTION
rooftop detention devices
Source: Wright-McLaughlin Engineers, Denver, Colorado

Figure 7. Roof Ponding Detention Ring.

Figure 8. Typical Parking Lot Drainage. Parking lots that are graded to drain runoff to the center of the lot offer little opportunity for detention ponding due to motorist inconvenience.

Retention/Detention Basins

Retention/detention basins slow runoff by holding it and releasing it at a controlled rate to downstream areas. Detention basins are intended to dry up after a storm, while retention basins may remain wet permanently; a natural pond can be called a retention basin if it is used to store runoff.

The space requirements for basins depends on shape and capacity of the design. Most basins are three to ten feet deep. Emergency overflow spillways are provided in case capacity is exceeded.

Both detention and retention basins will accummulate sediment and weeds that need removal. Retention basins may breed mosquitos. Fencing and landscaping may be needed for safety and aesthetics. The advantages of retention basins include their potential use for recreation, such as skating or boating.

Besides reducing the first flush effect, these basins can help water quality in other ways. If the storm flow is held long enough, some suspended solids may settle out though the basin design is crucial to achieve this settling. (See section on "Sediment Basins".) Oil and grease may rise to the top of the water in the basin, allowing removal by skimming or adsorption. Dry detention basins can be more readily cleaned than wet retention basins. The latter may actually concentrate contaminants as a catch basin does. At the onset of a storm accummulated sediments are stirred up, metals are dissolved and a poorer quality outflow can result.40

The cost of basins varies widely depending on size, land costs, etc. Maintenance costs range between a few hundred to a few thousand dollars per year.

Underground Storage

Underground storage facilities are less commonly used to store runoff. Holding tanks have been installed in rare instances, either where receiving waters would be particularly sensitive to stormwater drainage, or where closed drainage systems were not installed. Holding tanks are usually made of steel or concrete, though new fiberglass tanks used for underground gasoline storage could perhaps be adpated for use. Holding tanks are a very expensive option and should be considered a last resort.

Because underground tanks allow no outflow or infiltration of the stormwater, they must be pumped out regularly. This maintenance may be very expensive because, in many cases, the stormwater can be polluted enough to require licensed hazardous waste haulers to perform the pump-out, as opposed to the less expensive service provided by septic tank pumptrucks. Holding tanks are also useful for oil spill containment.

Although the use of these sealed tanks is rare, the town of Unionville, Connecticut prescribed their use in a local shopping mall. No storm drains serviced the mall, yet town officials were concerned that oil and grease from parking lot runoff would enter an adjacent creek. A licensed hazardous waste hauler services a 40,000 gallon-capacity concrete tank at the expense of the mall owner.41

Another underground storage structure consists of oversized storm drain pipes. These "pipe basins" are beginning to be used in certain areas around the country (e.g., Cleveland) to store stormwater. The design originated in Scandinavia twenty years ago. An enlarged pipe, which runs parallel to existing storm drains, adds water at a controlled rate as its storage capacity is filled. (See Figure 9.) This system reduces first flush shock by slowing flows; in a combined sewer the storage lessens the risk of excess flow bypassing the treatment plant.

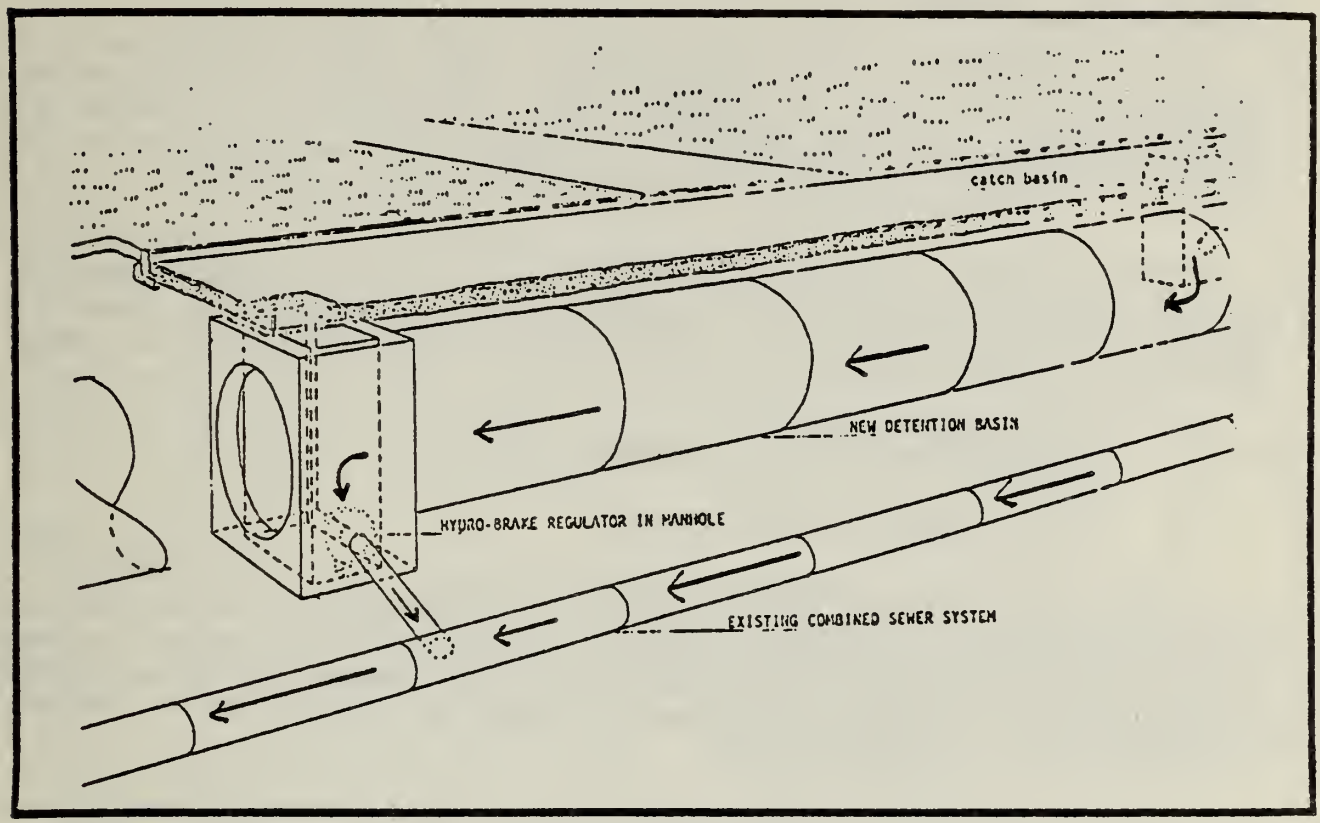


Figure 9. Detention Pipe Basin in Storm Drain.
Source: U.S. Environmental Protection Agency

This pipe basin can be adapted to allow some settling of suspended contaminants, though this is a secondary function. Maintenance problems will require catch basin cleaning methods due to debris buildup. No cost estimates were available for installation, though construction practices are the same as those for normal sewer construction.

RECHARGE/INFILTRATION

Using stormwater to replenish groundwater supplies by allowing runoff to percolate into the soil is an important factor that should be considered in any drainage design. But it is not wise to regard infiltration of runoff as a panacea for preventing contamination of surface waters and replenishing aquifers. Only clean stormwater should be employed as recharge.

Some soils have properties that purify stormwater as it seeps through the ground. Percolation rates vary with soil type: permeable sands and gravel remove fewer contaminants than less permeable loams and impervious clays. In general, fewer contaminants will be removed under the following conditions:

- shallow water table
- fast percolation rate (permeable soils)
- minor bacterial activity
- lack of vegetation and topsoil

Some contaminants, particularly dissolved ones, such as salt and nutrients, are more persistent than others. Adsorption and biodegradation are the two main processes that cleanse stormwater as it passes through soil. For example, heavy metals can be adsorbed onto soil particles. Some bacteria can biodegrade oil and grease. In general, stormwater is usually cleaner when it reaches the aquifer, but is it clean enough?

Aquifers used for drinking water supplies demand cleaner stormwater recharge than aquifers used for other purposes, such as irrigation. Towns solely dependent on groundwater for their water supply should be most interested in infiltration techniques that preserve groundwater quality. Utmost consideration should be given to well recharge areas or cones of influence.

Most of the recharge options discussed in this chapter were initially developed to solve flooding and erosion problems. They emphasize the use of natural drainage features - ditches, grassy swales, depressions - to remove runoff from developed areas. Engineers realized that natural drainage patterns consisted of horizontal and vertical components: overland flow away from the site, and infiltration down into the ground. Both components lessen flooding, but the vertical flow also provides recharge to aquifers.

Infiltration has been accepted to have advantages as a cleansing process for runoff too. Previously, most infiltration techniques were designed for quick percolation of large volumes of stormwater into the ground. These same techniques can be modified to allow rapid infiltration of clean runoff.

The basic premise for using infiltration methods for drainage is that hydrologic regimes are least disturbed when as much stormwater as possible can be retained on the site where it originates. Not only are underlying aquifers replenished, but less runoff is added downstream, which reduces downsteam flooding and erosion. Infiltration techniques can either be employed using open drainage methods or a combination. As a pollution control method, infiltration is more cost-effective than treatment systems.

One problem common to all infiltration methods is clogging. Pores in the soil must remain clear to allow stormwater seepage. Most suspended solids are deposited on the surface and thus are not a groundwater concern. Even the finest-sized solids settle out near the ground surface. Unfortunately, the ground is so effective at removing solids that their accummulation can interfere with the infiltration process. Sediment must be removed periodically to avoid clogging of the soil pores.

Recharge Basins

Recharge basins are simply ground depressions designed to collect runoff and introduce it into the soil. Natural depressions can be used or basins may be excavated. A recharge basin dries out, while a retention basin does not. A detention basin empties by releasing its contents downstream, a recharge basin will dry out through soil infiltration. These three types of basins may look similar, but they function differently.

A recharge basin is usually sited at the end of a drainage system, whether it collects runoff via open swales and ditches or via pipes. (See Figure 10.) A primary advantage of a basin is its flexibility of design. Many small basins can be scattered throughout a site or one larger basin can serve the entire area. (See Figure 11 for specifications of a typical basin.)

Several factors will affect a basin's design and effectiveness. Soils beneath the basin must be sufficiently permeable to allow infiltration; otherwise, the recharge basin becomes a pond. Topography is important because steep slopes make basin construction impractical. Finally, even if construction consists of nothing more than minor excavation and grading, costs can be important where land is expensive, particularly in urban areas. During dry weather large recharge basins can be designed for other uses, such as athletic fields. Problems of aquatic weeds and mosquito breeding should not occur because recharge basins are designed to drain quickly.

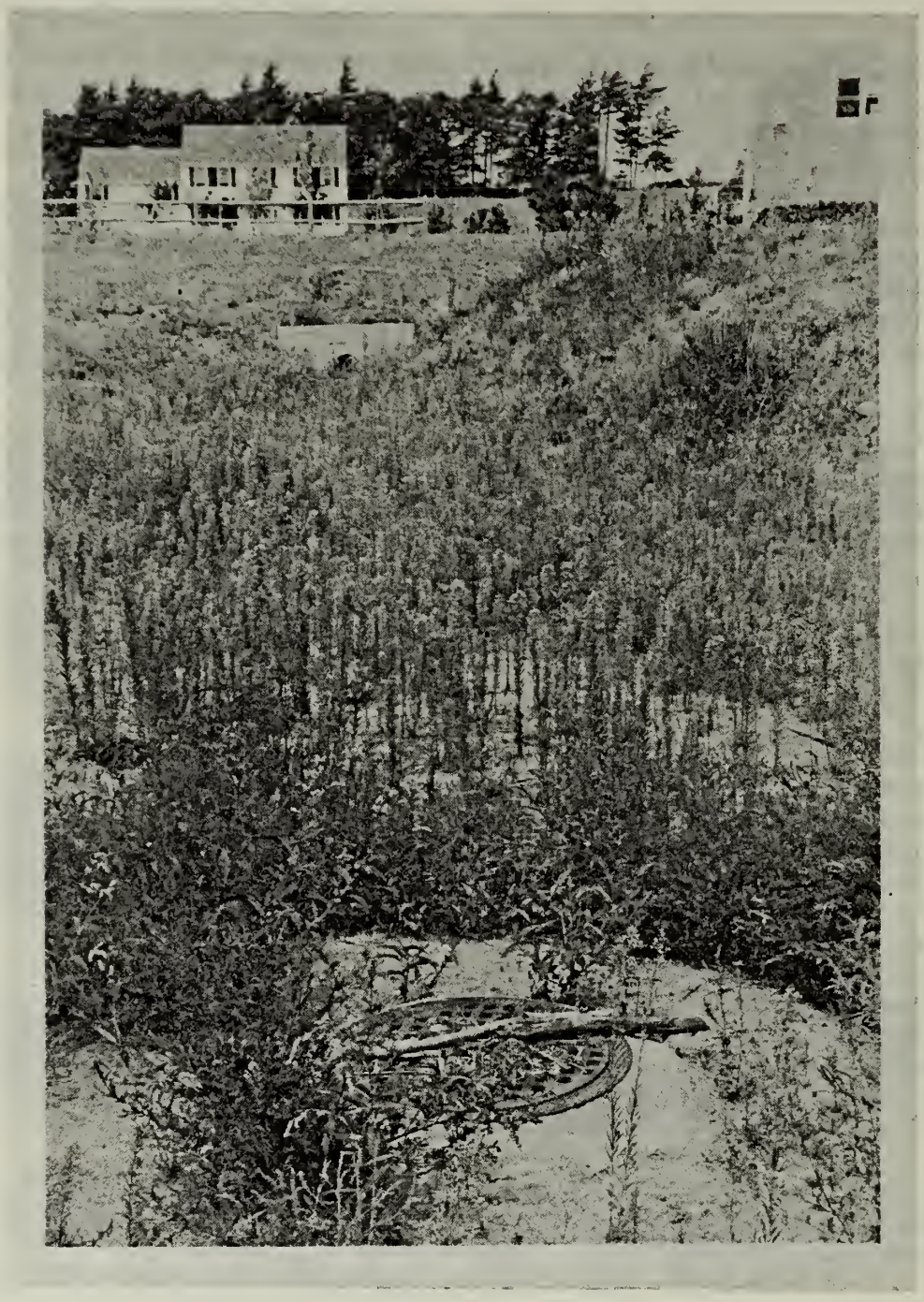


Figure 10. Recharge Basin serving Subdivision, (Duxbury, Mass.) Subdivision runoff is discharged through headwall (in background) to bottom of recharge basin. Weeds on basin floor may improve infiltration rate. Cover to dry well (in foreground) must be kept clean of debris to function properly.

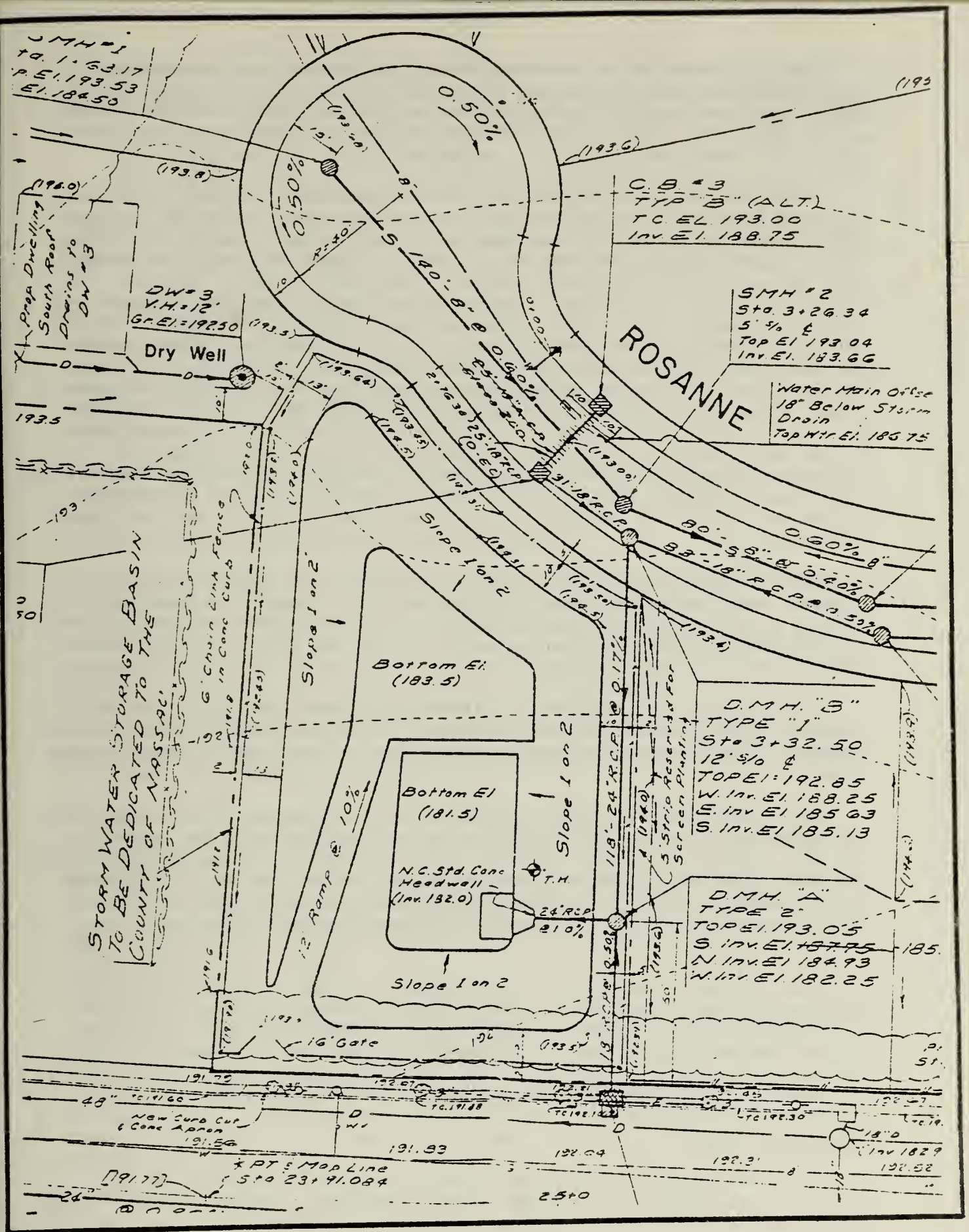


Figure 11. Engineering Design for Recharge Basin.

Source: Nassau County (NY) Department of Public Works

Since the 1930s, over two thousand recharge basins have been constructed on Long Island, New York. Most Long Island basins are an acre in size (though some occupy thirty acres) and range from ten to twenty feet in depth. Recharge basins infiltrate runoff rapidly through Long Island's sandy soil and they account for twenty per cent of all recharge to underlying aquifers. 42

On Long Island, all subdivision plans are regularly reviewed by the counties' Departments of Public Works for recharge basin design.43 Drainage area, topography and soils determine the capacity of each basin. Generally, the reviewers require that the basin be able to store and seep five inches of rain, if overflow into natural streams is available, or eight inches of rain where overflow is impractical. Test holes are dug at the site to ensure that a layer of permeable soil at least six feet deep underlies the basin. If not, precast concrete leaching drywells are installed in the basin floor to reach the sandy subsoil. Most basins in these subdivisions collect water from a closed system of pipes and catch basins serving the area. A concrete apron is placed at the pipe outlet on the basin floor to prevent scouring. The apron also has a small berm to slow the discharge velocities. A twelve-foot wide access ramp leading to the basin's bottom is built to allow maintenance equipment to remove accummulated sediment and debris. Maintenance is performed by the county because the recharge basin must be deeded to the county upon completion. Local laws require basins to be fenced for safety and landscaped for aesthetics.

While recharge basins have proven successful in replenishing aquifers, concerns have been voiced regarding their ability to purify stormwater. Most studies to date have analyzed the quality of the stormwater entering the basin and compared it with the ground water underneath the basin to determine the basin's treatment efficiencies.

A 1974 study found that much of the organic wastes and pesticides in stormwater were removed by the first foot of soil in the basin floor. 44 This finding was corroborated by another researcher who concluded that hydrocarbon removal occurred by soil adsorption and bacterial decomposition. 45

In a 1977 report, a basin draining runoff from the Long Island Expressway was suspected of contributing to chloride and zinc levels in the underlying aquifer. 46 Most recently, studies commissioned by the Nationwide Urban Runoff Program of EPA have found that the Long Island basins are very effective in removing heavy metals and pathogenic bacteria, but ineffective at removing chlorides from salt. 47 (A separate 1975 report on a recharge basin in California echoed the system's effectiveness in reducing heavy metals.) 48

Thus, recharge basins seem to be valuable in removing most contaminants, though salt-laden runoff should be diverted elsewhere to prevent chloride infiltration to the aquifer. EPA's position is that recharge basins offer "great promise" as an effective stormwater disposal alternative. 49

Costs for recharge basins vary widely, according to size.

Recharge Trenches

When the large space requirements of a recharge basin cannot be met, gravel-lined trenches can be used as an alternative. Trenches can be located on the margins of a road or parking lot without interfering with adjacent land uses.

Trenches can be constructed to intercept overland flow, usually at the toe of a slope, or in conjunction with a piped drainage system. Pipes running through the trench are perforated to trickle runoff along the whole length of the trench. (See "Perforated Pipe" section.)

Unless the existing soil is particularly permeable, an excavated trench must be backfilled with gravel around the pipe to ensure percolation. Both the trench wall and the perforated pipe are often lined with filter wrap or builder's fabric to prevent the pipe and gravel from becoming clogged with sediment. This fabric must be capable of transmitting water through it. 50

Because a clogged trench requires excavation for cleaning, it is better to remove suspended solids from the flow before it enters the pipe or trench. Sediment basins can settle out solids before the flow is discharged to the trench. For overland flows, sod filters covering the trench can remove large amounts of sediment and other pollutants. Gravel beds, such as those found in recharge trenches, have been recently suggested as good filters for hydrocarbons. 51

Recharge trenches with perforated pipe cost about $2,500 for each acre drained.

Leaching Catch Basins, French Drains, Dry Wells

Closed drainage structures can be modified or retrofitted to provide some infiltration of runoff. For example, catch basins are usually built with a solid impervious bottom of the sump. If the sump bottom is open to the soil, water held in the sump can seep into the ground. Leaching catch basins, however, prevent the operation of oil traps because a fixed water level must remain in the basin for a trap to work. (See "Oil Separators" section.) Underground runoff storage tanks can also be adapted to allow recharge, if soils permit. (See Figure 12.) Leaching catch basins and vaults should be cleaned more frequently than sealed basins and tanks because soil clogging interferes with percolation.

Dry wells function similarly to leaching catch basins, but they are endpoints, not leading to storm drains. Dry wells, also called French drains, are precast concrete perforated rings (about 4-6 feet in diameter) used to percolate stormwater. A dry well must be deep enough to penetrate sand or gravel subsoils to ensure infiltration. Like leaching catch basins, dry wells require cleaning to prevent clogging. (See Figure 13.)

Perforated Pipe

While impermeable pipes used in closed drainage systems are necessary for sanitary sewers, perforated pipe can often be used to transport runoff. Perforated pipe has small slots or round holes punched into its walls. It was originally used beneath land areas, such as athletic fields, to drain pockets of standing water. (Perforated pipe, for example, is used to drain water from the toe of the Blue Hills ski slope in Canton.) While this use is still common, perforated pipes have recently been recognized as providing recharge capability.

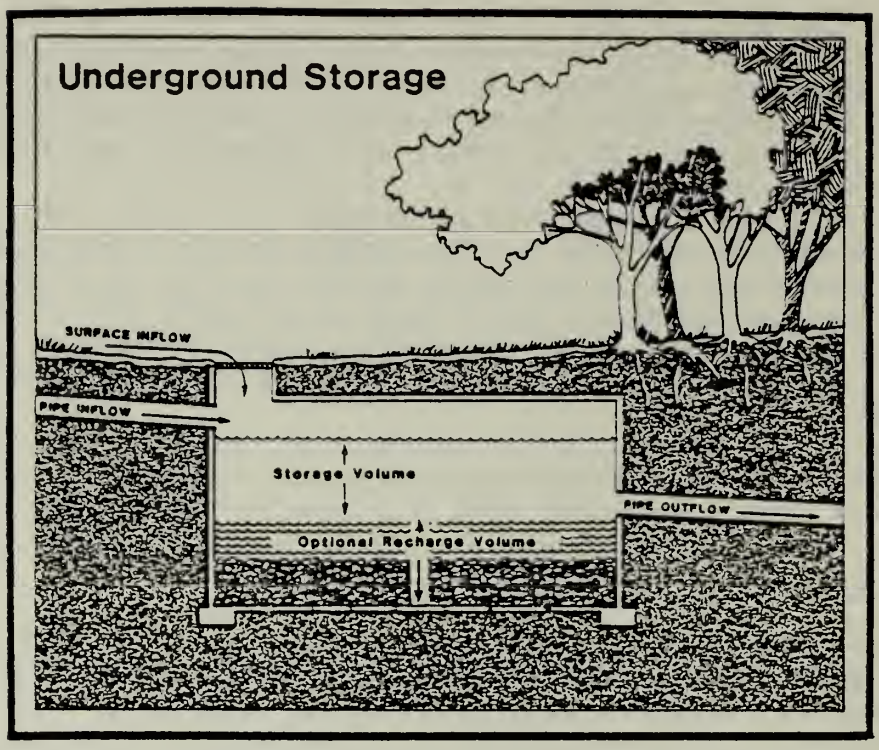


Figure 12. Underground Leaching Storage Tank. (Holes in bottom allow seepage.)
Source: Southwestern Illinois Metropolitan and Regional Planning Commission

Perforated pipes are available in diameters ranging from three to twenty-four inches (in plastic) to three feet (in aluminum). Similar storage and infiltration capacities can be designed by varying the ratio of perforated pipe to gravel backfill in a recharge trench. For example, a longer, wider pipe can be used to reduce the amount of gravel needed as backfill.

Clogging can be minimized by wrapping the pipe with builder's fabric. New pipes, made of a flexible polyethelene resin are less susceptible to severe temperatures than standard PVC plastic pipes and are more resistant to winter damage. These new pipes are also less expensive than aluminum ($2-$3 less per foot), and are expected to last at least fifteen years. 52

Use of perforated pipe in New England has lagged behind other regions, such as Florida and Canada, which have extensive experience with it. Holden, Princeton, Amherst, Springfield and Pittsfield are among the Massachusetts communities employing the use of the flexible polyethelene pipe.

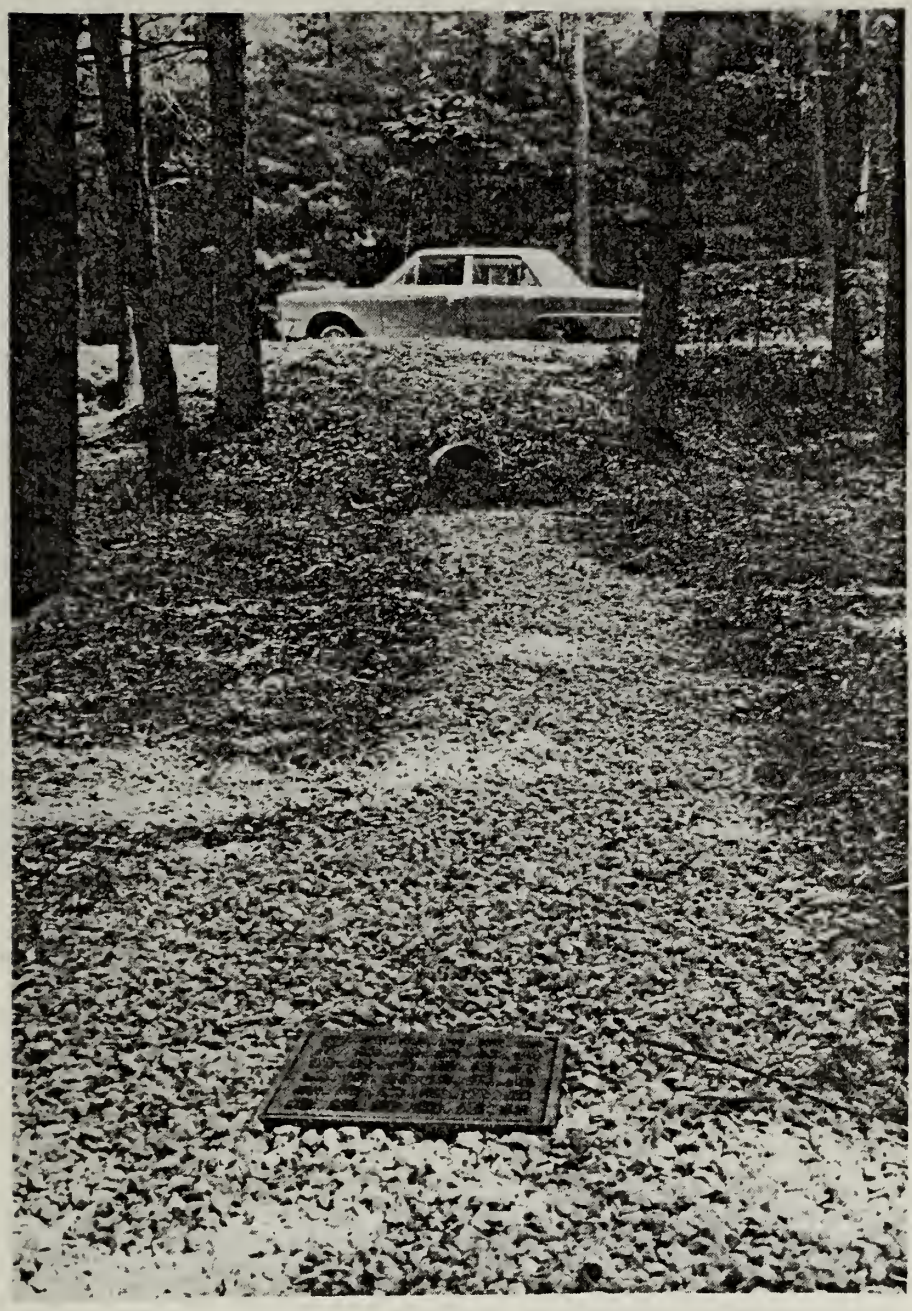


Figure 13. Dry Well, (Duxbury, Mass.) Street runoff is collected in catch basins and discharged through pipe (in background). Velocity is dissipated by flowing overland through crushed stone. Dry well (grate in foreground) located in woodland depression collects and infiltrates remaining stormwater.

If backfilled properly, perforated pipe can be used beneath roads and parking lots without damaging pavement integrity. 53 Very heavy loads may damage the pipe, but excessive weight can damage conventional pipe too. As with most recharge techniques, depth to groundwater is important to ensure that shallow aquifers will not infiltrate the pipe when the water table rises, thereby reducing storage capacity. Oil traps and sediment traps will reduce clogging of the pipes if installed at the head of the drainage system. Access to the pipe end will facilitate sediment removal.

Wetlands

Since the early 1970's, wetlands (defined here as swamps, bogs, wet meadows and marshes) have been recognized as providing flood-prevention functions. Wetlands act as giant sponges that can store and slowly release large volumes of water. Researchers have also learned that wetlands not only store, but treat some contaminants in runoff.

Wetlands can remove large amounts of nutrients from the stormwater by root uptake and soil microbes. (One wetland studied in Minnesota retained 78 percent of all phosphorus entering via runoff.)54 As much as 80-90 percent of suspended solids in runoff settle out as water slowly drains out of the wetland.55 Other treatment provided by wetlands may include neutralization of acid rains (except in acidic bogs), increased dissolved oxygen, and reduction of organic wastes.56 Wetlands have also demonstrated their ability to retain oil and heavy metals, particularly in muck soils.57

Due to their versatility in cleaning runoff, wetlands have been called "living filters". But the environmental conditions that govern a wetland are delicately balanced and much research still needs to be conducted on the long-term effects of contaminants collecting in wetlands. For example, it is known that too much water can inhibit microbial degradation in the soil. Chemical processes in a wetland may become overloaded by introducing too many contaminants.58 Salt marshes, in particular, are significant food sources and nursery grounds for many fish and shellfish, which may be vulnerable to the release of toxicants from the marsh over time. Thus, if stormwater discharge is proposed in a wetland for pollution control, the long-term consequences must be considered.

Grass Strips

In addition to soils, the amount and type of vegetation affects infiltration. Because of the penetration of roots, a thick layer of sodded topsoil provides an excellent medium for percolation. Grass has long been planted to stabilize exposed soil, particularly on slopes, and to prevent erosion. But sod also reduces the velocity of runoff and traps contaminants. As much as 90 percent of suspended solids in runoff can be filtered by grass, including 80 percent of the pollutant-laden fines.59 Grass roots are also effective for heavy metal uptake. In general, coarser types of grass, such as bermudagrass, are better filters. (See Figure 14.)

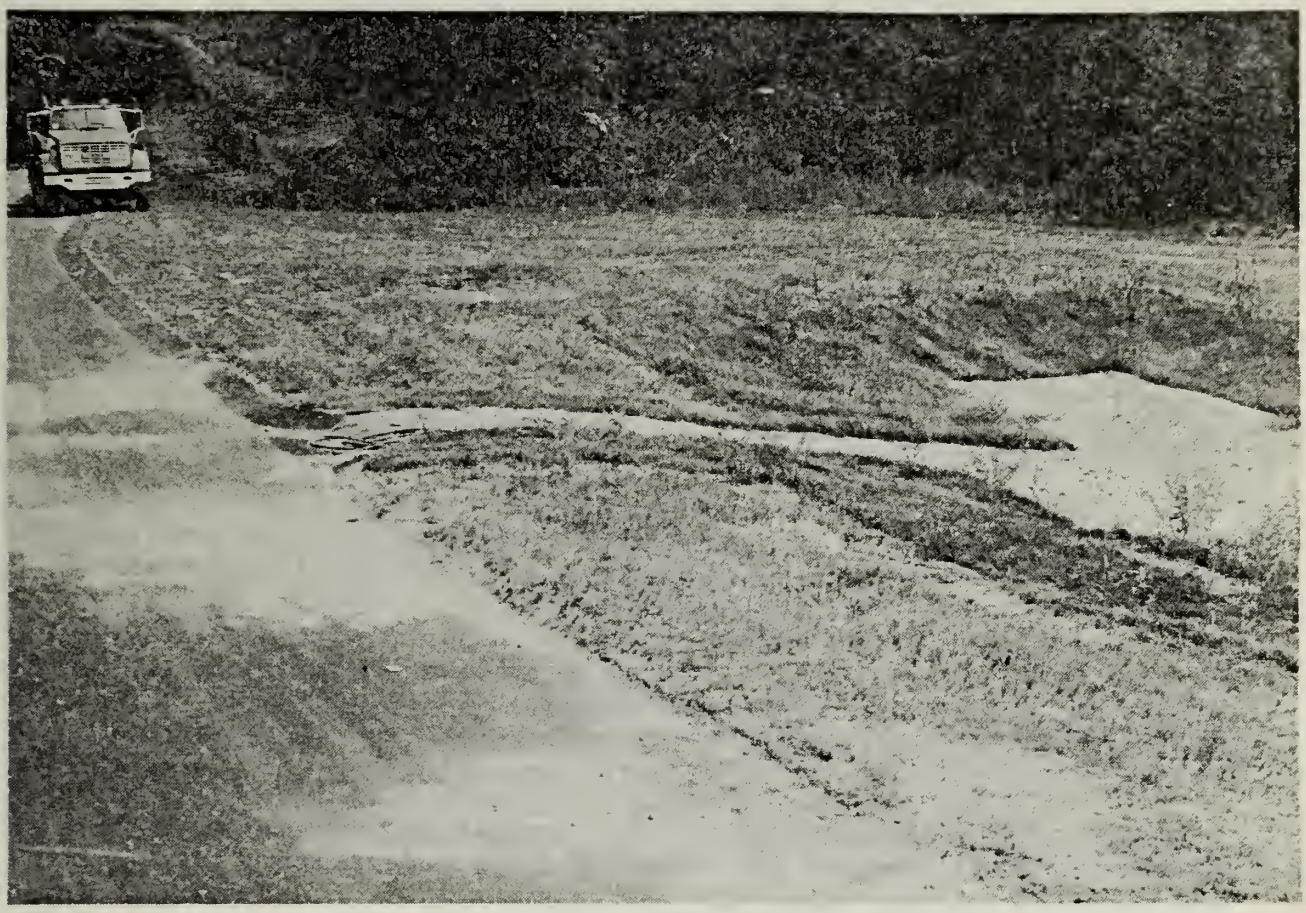


Figure 14. Grass Filter Strip, (Duxbury, Mass.) Thick sod, left unmown to increase coarseness, surrounds the slopes of this small recharge basin (also known as a velocity dispersion pool) to slow runoff and trap contaminants. Crushed stone fills the basin and waterway.

Grassed areas can be used either as conduits for channelling and infiltrating stormwater or as interceptors for trapping sediments. Grass can aid or buffer other drainage structures, such as when used as a filter bordering dry wells or recharge trenches. Disadvantages include preemption of some land from other uses and periodic grass mowing. Excessive sediment buildup on the grass must sometimes be removed.

Establishing grass by seed costs $2400-$3600 per acre. Sodding is more expensive. Maintenance costs $50-$100 per acre per year.

Lawn Aeration

Periodic aeration of lawns can be an effective means to increase infiltratiion. This practice has been used on golf courses for many years. Urban lawns and sod areas that receive constant or heavy weight loads have a very low infiltration rate in comparison to woodland and natural grasslands. Soil is compacted in these cultured areas due to human traffic and machinery. Many residential lawns are rolled every spring to pack down sod that has risen due to frost heaves over the winter. This rolling firms the soil, reducing surface infiltration and increasing runoff.

Lawn aeration is a simple process of puncturing short (three-inch long) holes into the grass by a rotating drum with spikes. The holes are too small to interfere with lawn use and gradually fill in and re-seed themselves, but meanwhile, they allow the soil to breathe and stormwater to recharge the underlying aquifer.

Porous Pavement

Roads and parking lots can be constructed using pervious materials to promote infiltration. Most commonly, this construction uses gravel or crushed rock called pea-stone as a surfacing material. Gravel is inexpensive and attractive for small parking lots and driveways. Likewise, in coastal areas shell fragments can sometimes be purchased in bulk to provide an aesthetically pleasing road surface. Gravel and shells promote infiltration, reduce runoff volumes and velocities, and store stormwater. These materials, however, are hard to snowplow in winter and are impractical for heavy traffic volumes.

Another alternative to conventional asphalt or concrete pavement is porous pavement. Porous pavement can either be open-graded asphalt or lattice-patterned concrete. Both alternatives allow stormwater to seep into the soil beneath the pavement, allowing aquifer recharge.

Open-graded asphalt looks like regular pavement, but contains very little dust or sand and there are more voids in the material. It is installed by normal paving procedures over large, angular stones, which provide a stable base for the pavement and a reservoir for the runoff. The thickness of the base depends on the reservoir capacity desired, but it need not be inherently thicker than the base required for conventional pavement.

Other comparisons between conventional asphalt and porous asphalt include wear and cost. Porous pavement is more prone to be abraded by vehicles' tires. It is also more vulnerable to degradation by air and sun because these elements can penetrate farther into the pavement. According to EPA-sponsored research in Rochester, New York,open-graded asphalt is as resistant to frost heave damage as traditional pavement. 60 Structural integrity is similar in both when stressed by heavy loads. Porous pavement is less expensive than regular asphalt if storm sewers must be installed to drain the latter. Costs for porous pavement range from $10-18 per square yard.

Concrete lattice is less popular as a porous pavement. Several patterns are available, but the lattice is not as strong as open-graded asphalt and should not be used in heavily trafficked areas. Lattice is perfectly suitable for sidewalks and is more attractive if grass is seeded in the holes. (See Figure 15.)

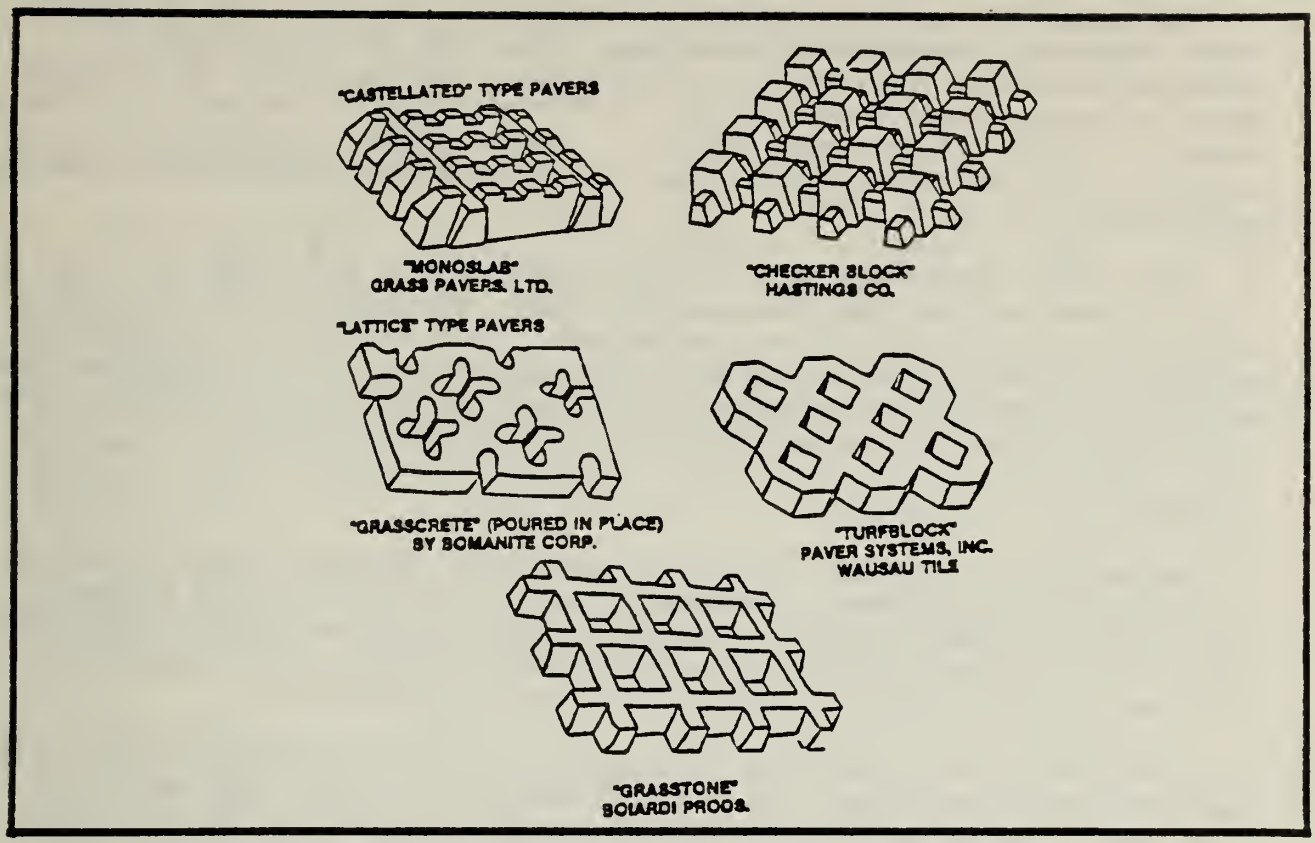


Figure 15. Concrete Lattice Porous Pavement Styles.
Source: U.S. Environmental Protection Agency

In general, the advantages of porous pavements are:

. increased storage and infiltration of stormwater
. reduced need for curbs, gutters, storm sewers
. preservation of natural drainage
. pavement provides greater friction, reducing hydroplaning, improving safety
. reduced puddling on road surface
. increased amount of water available to roadside vegetation. 61

The main drawback to porous pavement is clogging of the pores with runoff debris. Oil and grease from cars can block the surface voids as well as break down the asphalt cementing. Sediment can also clog the pores. The clogged holes can be cleaned by vacuuming or flushing, though vacuuming is preferred from a water quality standpoint.

In many ways, porous pavement can be seen as a more appropriate runoff method for parking lots rather than for streets. Structural loads are usually less on parking lots, deicing salt need not be used as frequently and most lots are relatively flat, which facilitates infiltration. In addition, vacuum sweeping can be performed at low speeds on parking lots. For parking lots that otherwise would drain into sensitive nearby surface waters, porous pavement can be an attractive solution for stormwater.

TREATMENT

The stormwater pollution controls discussed so far originated to perform other functions. Housekeeping measures, like street sweeping, began in response to public complaints about aesthetics. Runoff storage was initially a means to reduce flooding and erosion. Infiltration techniques were designed to prevent flooding and replenish aquifers. Gradually, each category was perceived as having some effectiveness in improving runoff quality by removing pollutants.

Most of the treatments in this next chapter can be described as "last-chance" options; they are used when other practices are not feasible or effective for removing targeted contaminants. Most are costly processes and require large volumes of stormwater to reduce treatment costs. Many have been adapted from sewage treatment plant technology and most are designed to remove only specific types of contaminants, such as suspended solids.

Sediment Basins

Sediment basins are very similar in design to detention/retention basins, but their function differs. A sediment basin is designed to trap suspended solids, while storage basins are mainly concerned with controlling peak runoff flows. Sediment basins do not prevent erosion, but they were originally designed to keep eroded soil from leaving construction sites.

A sediment basin removes solids by reducing runoff velocities long enough to permit particles to fall out of suspension to the basin's bottom. Velocities of incoming flows can be reduced by use of baffles in the basin. A riser pipe should be placed near the center of the basin. This whirlpool effect will force suspended solids to the outside walls of the basin. The vortex will be more pronounced if the basin is circular instead of square.

Basin maintenance includes periodic removal of the accummulated sediment. Costs are similar to detention basin estimates. (Capital costs for basin construction range from $10,000-$50,000 for each million gallons of capacity.)

Sediment basins are frequently used by the Massachusetts Department of Public Works (MDPW) when highways are under construction and large areas of soil are exposed. MDPW used to abandoned the tanks after completing construction and vegetation was planted to prevent erosion. The agency now intends to make the basins permanent in some areas, such as for Route 25 in Wareham and near the Wachusett Reservoir along Route I-190. The future practicality of sediment basins will depend on land availability because large amounts of land are needed to provide adequate settling for runoff from major projects.

Many researchers have studied the sediment basin's effectiveness in removing suspended solids. The consensus is that sediment basins are efficient for suspended solid reduction, but are of only marginal value for other runoff contaminants.62 The removal of fine particles depends on the settling time

offered by an individual basin. Because many other contaminants are adsorbed onto the fines, it is important that the basins be large enough to allow long enough detention times to promote settling of the fines. Sediment basins should drain dry in between storms because standing water can transform settled metals into dissolved form, making them more toxic and harder to treat.63

Salt Evaporation Basins

Recently, great progress has been made in solving the problem of road salt storage. Almost all of MDPW's salt stockpiles have been enclosed in storage sheds.64 Most towns also cover municipal piles. The sheds keep rain from dissolving the salt, which would produce runoff brine at the site.

Nevertheless, at most depots dumptruck loading of the salt is conducted outside the confines of the sheds. Inevitably, some salt is spilled onto the pavement during loading. Salt storage shed doors are left open to dry the piles in clear weather, but dampness inside the shed will also cause small amounts of brine to form and flow outside the shed walls.

This accummulation of brine near enclosed stockpiles is clearly minor compared to brine volumes produced by exposed stockpiles. Nevertheless, by state law storage sheds that are located in sensitive water supply areas must take precautions to prevent salt contamination, (MGL c. 85, s. 7A).

Salt evaporation basins are one method to control salt-laden runoff. They are simply shallow, impervious depressions used to collect runoff at salt storage sites. Evaporation removes the runoff, leaving a salt residue (and any other pollutants in the runoff). The basin's location is important. It should be downgradient of the rest of the site, so the brines will drain into it. Collection gutters can be installed around the base of the shed, if necessary. The basin should also be in the open, so maximum sunlight can speed evaporation. Black impervious liners, such as asphalt or vinyl, promote evaporation because dark colors absorb more sunlight.

The major problem with salt evaporation basins is their space requirements. Calculations by the Massachusetts Department of Public Works have determined that large amounts of acreage are needed to promote evaporation in a shallow basin.65 Nevertheless, the MDPW has installed small experimental salt basins at its salt storage sites in Avon and Norton. A third has been proposed in Freetown. All were designed to prevent salt contamination of important nearby water resources. The basins already constructed are about 50 feet long, 30 feet wide and four feet deep. MDPW estimates the basins cost several thousand dollars to build.66 Impervious asphalt lines the basins, which are cleaned out yearly or as conditions warrant. (See Figure 16 and 17.)

If salt evaporation basins can be designed to hold only the brine generated around the shed, the volume of runoff will be less and the basin will require less space. If the design succeeds, the basin can represent an inexpensive alternative to sealed underground tanks. The contents of such tanks would have to pumped and trucked out of the area regularly. (See section on "Underground Storage".)

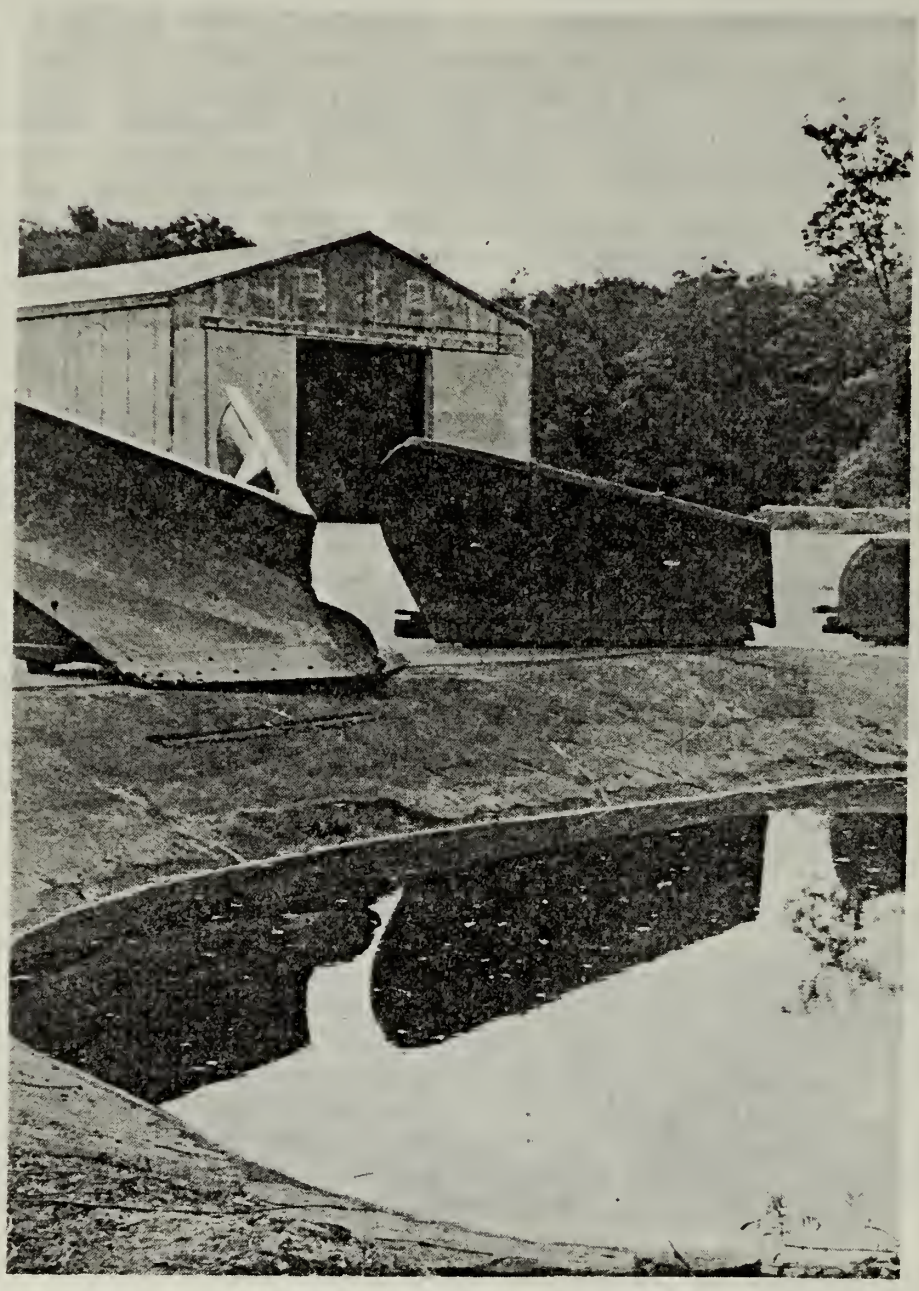


Figure 16. Salt Evaporation Basin, (Avon, Mass.) Briny runoff from vicinity of salt storage shed (in background) drains to shallow basin (in foreground) for evaporation.

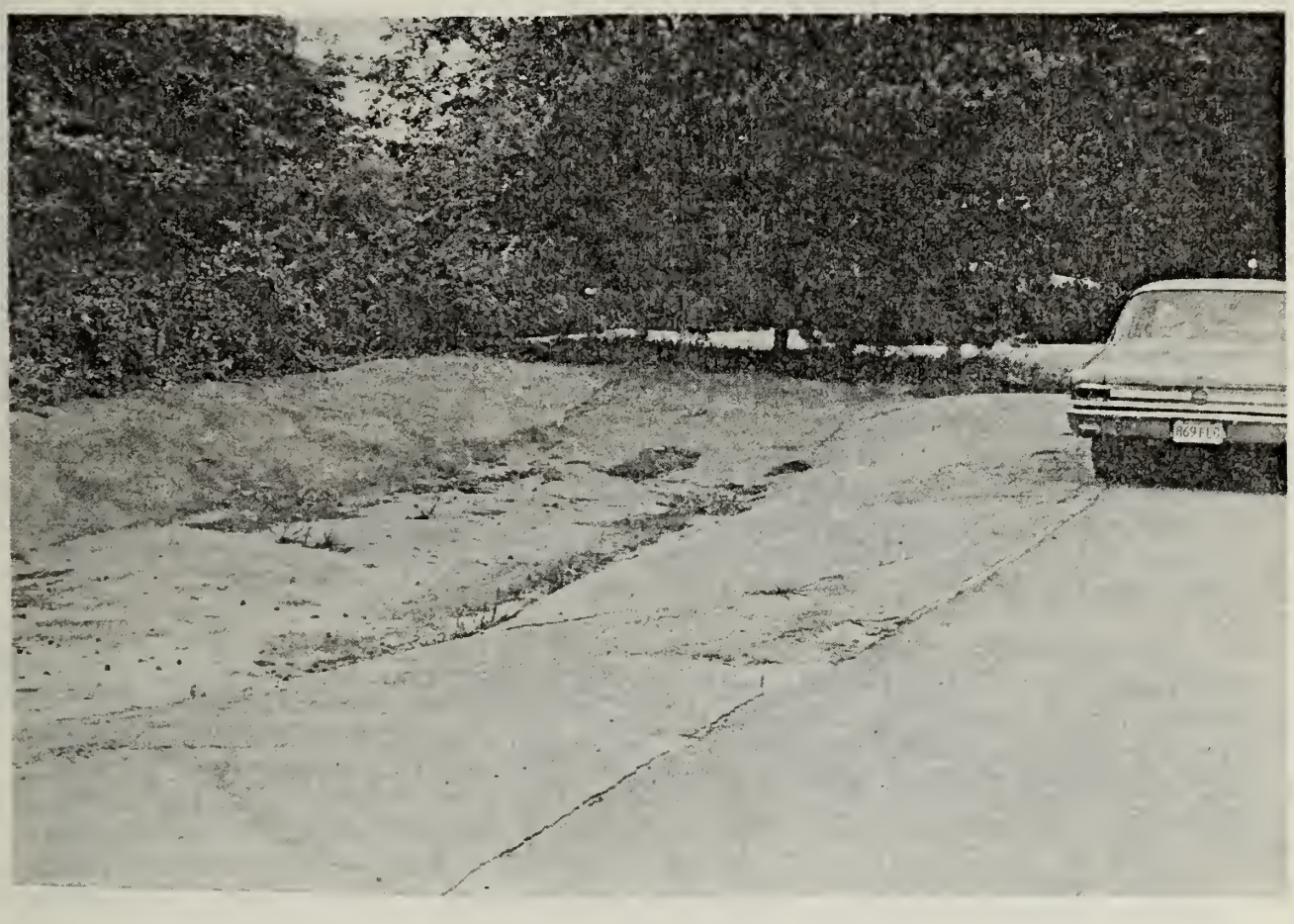


Figure 17. Salt Evaporation Basin, (Avon, Mass.) Dried-out asphalt basin has developed cracks that will need resealing to remain impervious.

Salt basins are most effective for collecting runoff from a small site, so they are impractical for use along roadways where deicing salt is applied. For long, linear drainage areas, such as highways, an alternative collection system called snow berms may be more feasible.

Snow Berms

Snow berms, a new development in drainage design, are part of an impervious conveyance system used to carry all highway runoff away from a particular area, such as an important wellfield or reservoir. Snow berms consist of impervious pavement, running parallel to a road's shoulders, graded to drain all runoff from the road and channel it laterally in one direction. The berms extend twenty to thirty feet out from the edge of the shoulder and look like wide asphalt ditches running alongside the road. They are wide enough to collect salt-laden snow thrown over the road shoulder by snowplows.

Snow berms are a conveyance system, not a treatment method. But because desalinization of runoff is usually impractical, transporting brine away is the only feasible means to protect freshwater resources. Snow berms are constructed only with pollution in mind because, by definition, they preclude recharge or storage functions.

Snow berms were first installed in 1982 along parts of Route I-90 near Worcester, in response to concerns about possible salt contamination from the highway adjacent to Metropolitan District Commission's Wachusett Reservoir. EPA required MDPW to construct snow berms along crucial parts of the highway shoulders in order to convey the road runoff to less sensitive land and water areas. No other treatment, however, is provided at the stormwater discharge point. The snow berms were painted green for aesthetic purposes, but some observers complain that the wide expanse of road pavement and berm asphalt makes the route "look like an airport".67 In addition, guard rails were placed not at the road's shoulder, but at the far edge of the snow berm because it was feared that cracks would develop in the pavement at the base of the guard posts, breaking the impervious seal provided by the berms.

For aesthetic reasons, the MDPW wanted to cover the snow berms with three feet of soil. But the agency was thwarted because critics claimed that if the berms were covered, monitors could not determine by visual inspection whether the berms were cracked or leaking. No formal research has been proposed on the effectiveness of snow berms at Wachusett, but the EPA is monitoring their use.68

One research project on snow berms is being developed by MDPW. After lengthy delays, extension of Route 25 from Wareham to the Bourne Bridge at the Cape Cod Canal will resume construction in 1984. One reason for the delay was that opponents argued the proposed route would traverse sensitive watersheds and public wellfields. The MDPW, in cooperation with U.S. Geological Survey hydrologists, have designed a study to assess the value of snow berms and other drainage systems in protecting local water supplies.69 Baseline data has already been collected on existing aquifer quality before construction begins. Salt and other contaminants will be measured in monitoring wells for five years after the highway is opened in 1986. Pollutant levels generated by highway use will be compared with pre-construction aquifer quality for three types of drainage systems planned for use along different segments of the road:

- conventional closed drains (catch basins, pipes)
- open, natural drainage (overland flow, infiltration)
- modified snow berms

The modified snow berm designed by MDPW is shown in Figure 18. The impervious berm will be covered with three feet of sand and other permeable soils and overlain with loam topsoil, grass seed and sod. A perforated pipe packed with gravel will collect and transport runoff as it percolates through the grass and soil to the base of the berm.

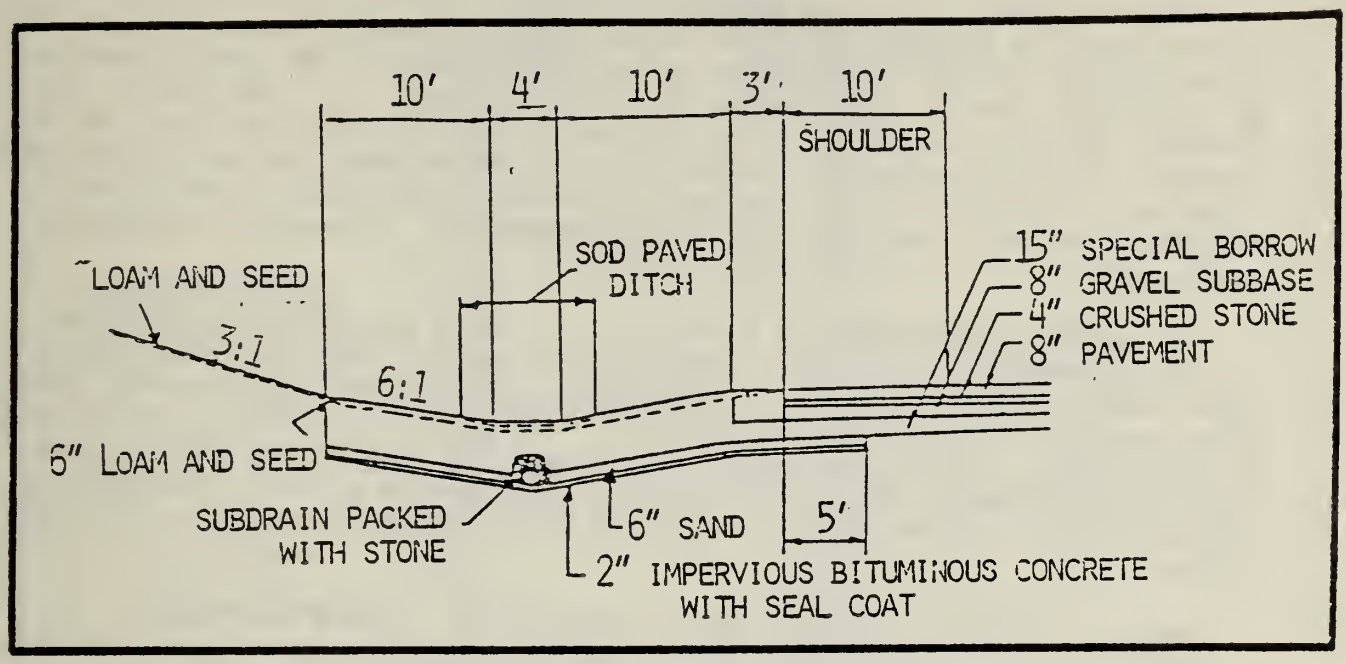


Figure 18. Modified Snow Berm for Highway Drainage
Source: Massachusetts Department of Public Works

Studies have shown the effectiveness of soil filtration for removing stormwater pollutants.70 Seeping three feet down through grass and soil before reaching the subdrain in the berm may be far enough to remove some suspended solids, metals, bacteria and hydrocarbons. Nutrients and salt would remain a concern, but it is hoped that the Cape Cod Canal can be used as a receiving water for the berms's effluent. Briny runoff should not harm the Canal's salt water.

The modified snow berm seems perfect for Route 25's conditions. Ponds and streams in the area are protected because runoff will be percolated through soil above the berm. Aquifers will be protected because infiltration will be halted by the impervious berms. Marine receiving waters can best accommodate saline runoff.

The main drawback to snow berms is their cost. To be effective on divided highways, snow berms must be installed along each outside shoulder and across the entire median. Costs can average $750,000 for each road mile or $1,500,000 a mile for berms along the four shoulders of a divided highway (1981 estimate).71 Berms require wider rights-of-way and higher land costs and coastal waters may not always be nearby to receive snow berm outflows. Finally, snow berms prevent retention of runoff on the site, so aquifer recharge is slightly reduced.

Nevertheless, snow berms represent a milestone in highway drainage design. Their use should be evaluated whenever highways cross vulnerable water supply areas. They are not difficult to construct and can be built with existing technology.

Oil Separators

Concentrations of oil and grease in runoff can range from 10 parts per million (ppm) in residential areas, to 40 ppm on highways, to over 50 ppm in large parking lots.72 While these average loads seem small, hydrocarbons can be significant runoff contaminants for several reasons. In addition to its inherent toxicity, oil often contains other toxic compounds, such as lead and benzene. Oil films also cause aesthetic problems in receiving waters and harm waterfowl. Finally, oil may coat and clog many of the runoff control and treatment devices, impairing their effectiveness and increasing maintenance requirements.

The primary development in technology to remove oil from runoff is the gravity separator or oil trap. The device is usually used in a catch basin or other underground holding tank connected to a storm sewer. When runoff flows into a basin, oil will float to the top, while gravity sinks the heavier water to the bottom. The oil is trapped in the basin as long as the outflow pipe drains water from the bottom of the basin. The design of the discharge pipe and the constant liquid level left in the basin prevent the oil from draining out too.

Several different oil trap designs are in use. Figure 19 shows a "T"-outlet type of separator. The "T"-outlet is easy to install and can be used to retrofit existing catch basins. It is frequently installed in catch basins draining land surfaces that have recently experienced an oil spill. Problems associated with the "T" design include the emergency overflow pipe elbow, which would allow any trapped oil to overflow with the cleaner stormwater during excessive flows.

Another design, called the MDC trap, is preferred by Massachusetts pollution control officials. (See Figure 20.) This trap also is used in catch basins, but is more difficult to install in existing basins because excavation would be required. This inverted outlet pipe design is required by the Metropolitan District Commission for any catch basin needing a drainage easement to discharge into MDC waterways. The MDC typically requires their use in closed drainage systems serving public or private parking lots. The state Division of Water Pollution Control also prefers this design.

A third type of trap appears more sophisticated. The American Petroleum Institute, an oil industry association, recommends a baffled tank to separate oil from runoff. (See Figure 21.) The width of the three-chambered tank precludes its use in most narrow catch basins. Flow is looped through the tank by means of baffles, which quell the turbulence in the tank and allow oil to float on top, primarily in the middle chamber. Outflow is decanted by a "T"-type pipe in the third chamber and suspended solids are deposited on the tank bottom.

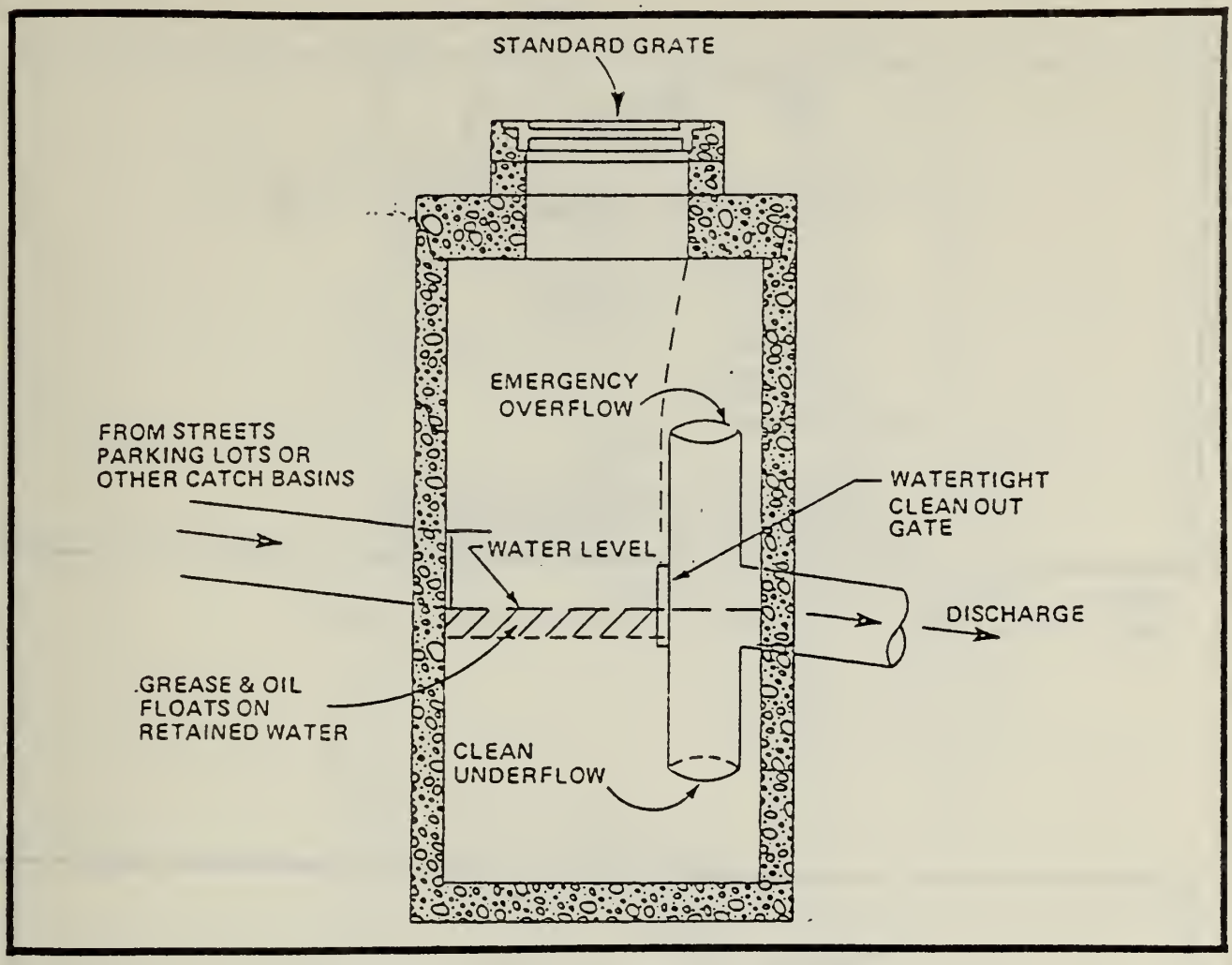


Figure 19. T-outlet Oil Trap.
Source: Municipality of Metropolitan Seattle (WA), Water Quality Division

Several municipalities have local regulations concerning the use of oil separators. The City of Newton, for example, has engineering guidelines that require oil traps for any storm drains leading to watercourses, such as the Charles River. (See Figure 22 for Newton's standard design.) In 1983 the Planning Board in the neighboring town of Needham amended its subdivision regulations to require developers to conform to oil trap specifications established by the town's Engineering Department in order to end confusion about acceptable designs. Little research has been conducted on the capabilities of any of these types of oil traps. To be effective, the trapped oil and grease must be removed after every storm so that subsequent storms will not resuspend or emulsify the oil again and discharge it through the outlet.73 Resuspension can be lessened by the use of sorbent pads to soak up the oil. (See next section on "Sorbents".)

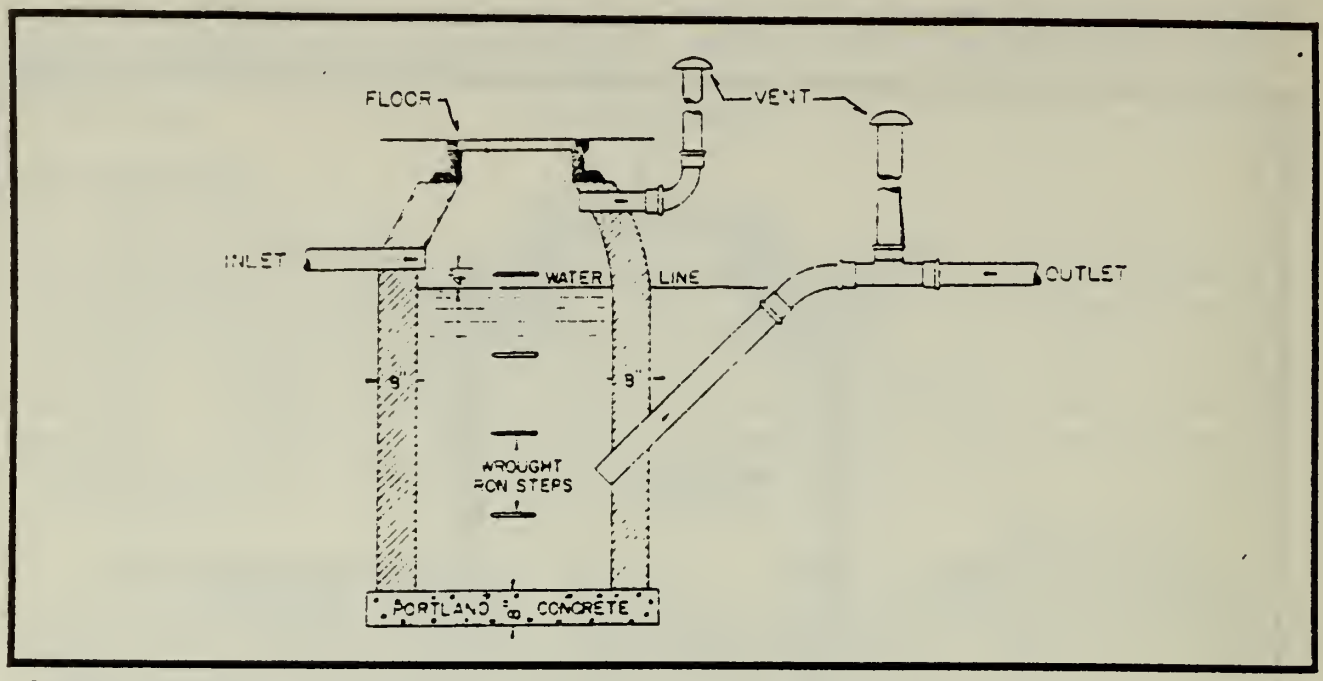


Figure 20. MDC Oil Trap.
Source: Massachusetts Division of Water Pollution Control

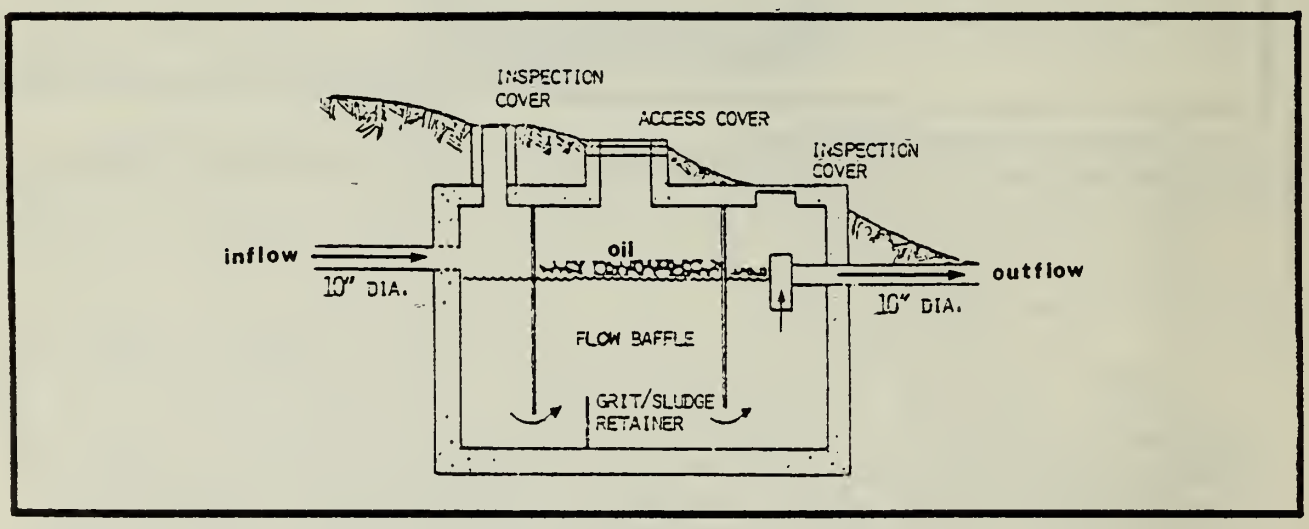


Figure 21. American Petroleum Institute's Oil Trap.
Source: adapted from Municipality of Metropolitan Seattle, Transit Department

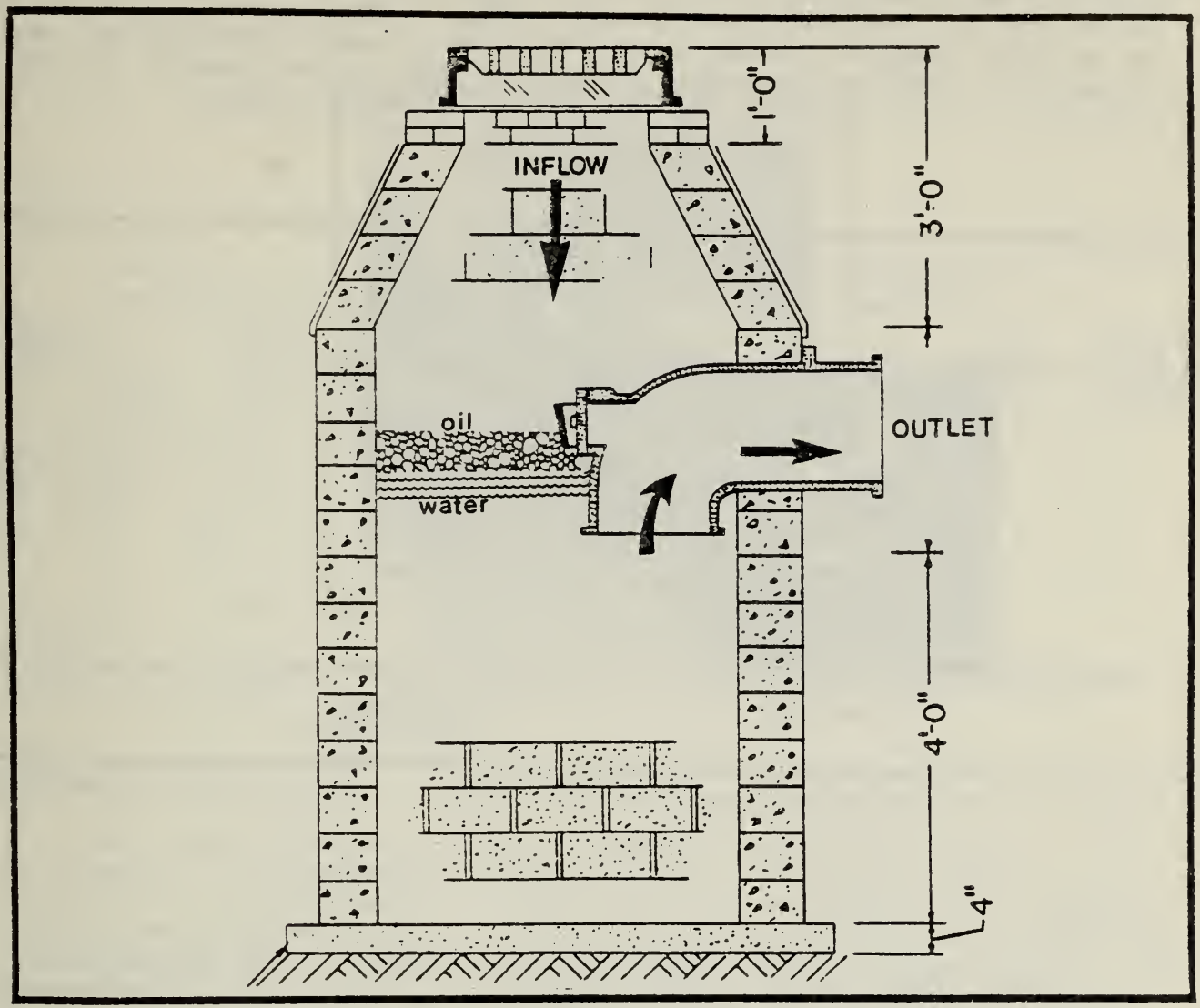


Figure 22. City of Newton Oil Trap.
Source: Newton (MA) Engineering Department

In 1983 a University of Washington study examined the use of API separators (unaccompanied by sorbent pads) serving runoff from a fifteen acre bus service depot in suburban Seattle.74 Stormwater collected in a closed storm drain and flowed through one API tank to a retention pond. A second API trap treated discharge from the retention pond before the outflow finally emptied into a natural creek. The effluent was not found to have appreciably lower concentrations of oil than the raw stormwater. The API type of oil trap was not considered effective by itself.

The newest oil separator does not rely solely on gravity. Called a coalescing plate separator, the device evolved from treating industrial wastewater and shipboard bilge water. Packs of corrugated plates coalesce small oil and grease droplets into larger drops, which float more readily and are skimmed off the tank's top (see Figure 23). A manufacturer's description of the plate separator claims it can produce an effluent containing less than 10 ppm of oil, but no independent assessments have yet been made.75 The major drawbacks to this device are its high cost and possible clogging.

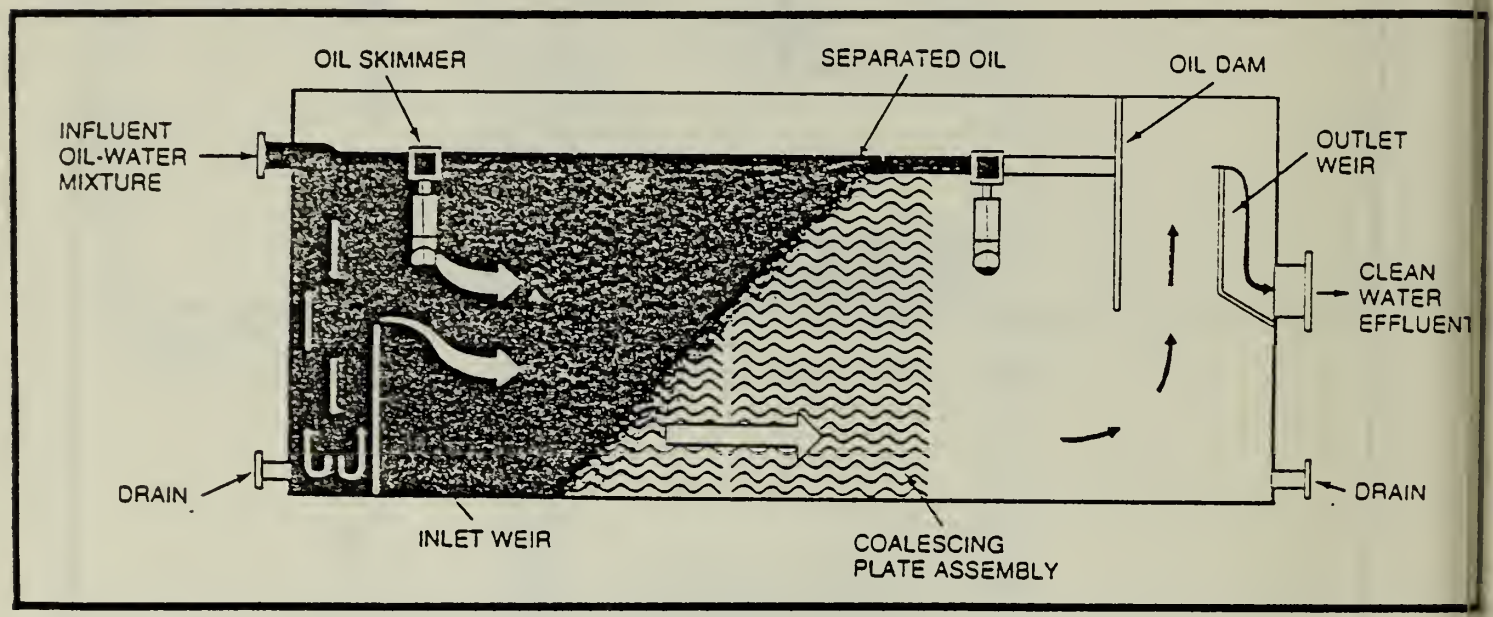


Figure 23. Coalescing Oil Trap. Source: Fram Corporation

Sorbents

Sorbent pads were developed to soak up oil spills. They are made of synthetic fibers, such as polypropylene, that are oleophilic or "oil-liking". They adsorb oil onto the sponge-like material, while repelling water. The pads are used to mop up small spills when the concentration of oil is not great enough to merit pumping by vacuum hoses or other mechanical means. Because they can work effectively on small loads of oil, sorbents can be used to remove normal amounts of hydrocarbons in runoff.

Sorbents are most often used in conjunction with oil trap catch basins. The sorbents generally come in flat pads or mats that are one square foot in size, but they can also be in pillow or granular form. Pads are cheaper than pillows, but become saturated more quickly. Both float on the surface where the oil collects and so should not clog the outlet of an oil trap. For use in a conventional catch basin (without a trap), the sorbent must be secured, usually by tying it so it cannot plug the outlet pipe. The sorbent material will adsorb only oil products so other pollutants must be removed by other means. (See Figure 24.)

Figure 24. Sorbent Pillows in Drain. Source: Conwed Corporation

Local conservation commissions throughout Massachusetts, including the one in Barnstable, are beginning to require oil traps with sorbent pads in their "orders of condition" governing construction near wetlands. This practice may soon become widespread because it is an inexpensive, visible means of combating runoff contamination. Developers often agree to install sorbents because they are relatively inexpensive. (A sorbent pad costs only about one dollar.)

Sorbents, however, cannot be installed and then ignored. Although made of synthetic materials, sorbents will begin to degrade after several months of use. Constant immersion in stormwater will cause them to become waterlogged. The pads will continue to float while waterlogged, but their adsorption of oil is impaired. Eventually, oil will begin to leak out of the sorbent and back into the water.

Consequently, a regular maintenance program must be established to service the used sorbents. Because sorbent pads are contaminated by oil, they are classified as a hazardous waste in Massachusetts. Some towns are afraid this hazardous waste classification means that they must hire specialized firms - at great cost - to remove and replace sorbents in a trap. (Companies must be licensed by the state Department of Environmental Quality Engineering (DEQE) to handle and transport hazardous wastes.)

DEQE, however, has expressed a willingness to consider establishing a policy that would allow towns to conduct sorbent maintenance in oil traps draining public roadways.76 DEQE already allows local landfills to collect and store waste oil without obtaining a hazardous waste license as long as the oil is transported off-site by licensed contractors at regular intervals.77 A similar policy could permit communities to collect and properly store small quantities of contaminated sorbents until they are transferred to hazardous waste haulers for disposal.

Some of these licensed firms already have scheduled routes for cleaning oil from catch basins on private property, such as shopping malls.78 Depending on the severity of the problem, maintenance is performed daily, weekly, monthly or semi-annually.

The firm arrives at the site and first takes a water sample from the top and the bottom of the trap to determine oil concentrations. If major concentrations exist, the sorbents are removed and the entire contents of the catch basin are pumped into a vacuum truck. Small sheens of oil are cleaned by removing the pads and drawing clean sorbents across the water's surface to extract residues. Spent sorbents are placed in sealed drums and transported out of state (typically to New York) because there is no permanent oily waste disposal site in Massachusetts. Out-of-state transportation costs represent the major component of cleanup expenses.

A significant problem confronting local boards that require sorbent installation is how to monitor a private oil trap to ensure that it is serviced regularly. This proof can be provided in two ways. First, because hazardous waste "manifests" are required for any transportation of oil wastes in the state, written verification should exist for every oil trap cleaning that is conducted by a DEQE-licensed firm. Copies are retained by the client, the hauler, the state and the disposal site. The client, or catch basin owner, could be required to send a copy of the manifest to the town board each time the trap is scheduled to be cleaned.

Secondly, if collecting receipts for each cleaning is too cumbersome for both the town and the client, the client could be required to furnish only a copy of its annual contract with the licensed hauler, which establishes the cleaning schedule (daily, weekly, etc.) Modifications to the contract would also be sent to the town.

Various owners of oil traps within the same town, or in adjacent towns, could save money by negotiating collectively for cleaning services from the same company. The cleaning cost per unit should be lower because the licensed hauler makes fewer trips and serves more traps in the same area. By consolidating scheduled routes, the significant transportation costs should be reduced.

Air Stripping

None of the treatment techniques described so far have been proven effective in removing chlorinated hydrocarbons, such as some solvents, and PCB's, which are particularly toxic. While the concentration of such compounds in runoff is usually low, their harmful effects can be magnified as they accummulate.

One advanced technological process to remove these chemicals is called air stripping. Water is cascaded down through a "stripping tower" full of a filtering material, while air is blown up from the tower's bottom to counter the water's flow. Water exits the tower and receives secondary treatment through a tank of activated carbon used as an adsorption filter. One manufacturer's literature reports removal efficiencies of 96 percent for benzene, toluene and other solvents like trichloroethylene.79 PCB's, phenols, pesticides and acids can also be removed. (See Figure 25.)

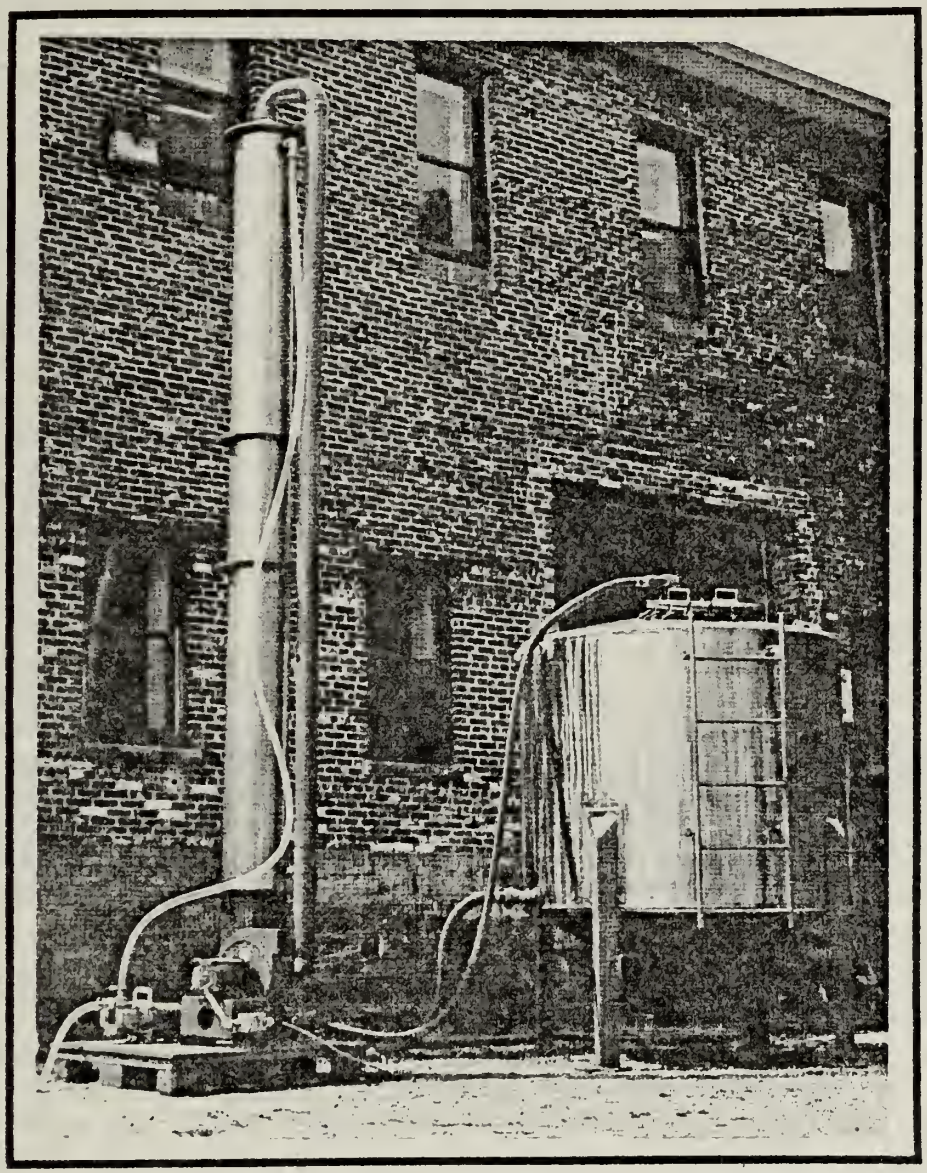


Figure 25. Air Stripping Devices. Source: Oil Recovery Systems, Inc.

The main problems with air stripping are its high cost and inability to handle relatively large flows usually associated with runoff. However, used in conjunction with storage facilities, such as sediment basins, air stripping could treat stormwater that is destined to reach acutely vulnerable water resources, such as a reservoir used for a drinking water supply.

Sewage Treatment Technology Adapted for Cleaning Stormwater

Microstrainers

Many types of screens, sieves and strainers have been developed to remove contaminants from runoff. Microstrainers (ultrafine screens) are most frequently used as the main treatment or "polishing" device to remove suspended solids. Their effectiveness is highly variable, ranging from 20 to 99 percent depending on mesh size, screen size, flow rates, size of particles and clogging.

A microstrainer uses finely-woven stainless steel mesh wrapped around a rotating drum. The drum is half-submerged in the stormwater flow and half-exposed to the air. As the drum revolves,it forces stormwater out through the screen. Trapped sediment is backwashed, using strained stormwater, from the exposed top of the drum into a trough for conveyance to a sanitary sewage treatment plan.

Microstrainers require little space, can be used on separate storm drains or combined with sanitary sewers, are relatively economical and can be run automatically. Suspended solids in stormwater are less likely to clog the microstrainer's mesh than sanitary sewage. Slimes forming on the drum can be removed by disinfection. Construction costs to treat one million gallons per day vary from $5,000 to $12,000.80

Dissolved Air Flotation

Dissolved air flotation removes suspended solids by reverse sedimentation. Air is pumped into the bottom of a stormwater storage tank and fine air bubles attach themselves to particles in the water. The combined buoyant force of the particle and the bubble causes the particle to float to the surface where it is skimmed off. This process can be very effective for removing solids. Its efficiency can be enhanced by using chemical polymers to flocculate (or combine) the fine sediments. The costs for dissolved air flotation are high at the present time.81

High-Rate Filtration

Filter beds have long been used to polish sewage effluent before it exits the site. By increasing the rate at which wastewater can flow through the filter bed, the large "shock" loads of stormwater runoff can also be accommodated. A deep bed of coarse sand and stone filter has proven effective in removing large amounts of suspended solids, organic wastes, bacteria and phosphorus from runoff. Advantages of high-rate filtration include its automated design, small space requirements, and ability to handle wide variability of flow rates. Chemical coagulants improve pollutant removal.

Disinfection

Disinfecting runoff can be a major undertaking because of the amount of disinfectant required to kill bacteria in large volumes of stormwater. Nevertheless, disinfection is the best and most effective means of removing pathogenic (disease-causing) bacteria from stormwater. Virtually all bacteria can be eliminated by disinfection.

Chlorine and hypochlorite are the two most common disinfectants. Some treatment plants near coastal water have found it cheaper to produce their own chlorine (by a process using seawater and electricity) than to buy the large amounts of disinfectant. On-site production also reduces the safety risks posed by transport of liquid chlorine.

A normal contact time of fifteen minutes for disinfectant to kill bacteria can be reduced to two minutes by new high-rate disinfection techniques. High-rate techniques include rapid mixing of the disinfectant and stormwater by using corrugated baffles to induce a turbulent flow in the treatment tank.

Swirl Concentrator

Several devices provide high-rate sedimentation of stormwater pollutants. A swirl concentrator (see Figure 26) is designed to remove suspended solids when installed either within or at the end of a storm drain. The device separates solids from liquids by swirling the flow through a circular chamber. The removed solids exit in concentrated form to a sanitary sewer or holding tank, while the relatively clean remaining flow can be discharged to receiving waters or be treated further.

The swirl concentrator separates solids from runoff at a fraction of the time needed by sediment tanks or dissolved air flotation. No new space is required because the device can be installed in existing sewer lines. A swirl concentrator is considered highly cost-effective to install and, because there are no moving parts, inexpensive to maintain.

The swirl concentrator is more effective in removing the larger solids than the fine particles, which carry most of the more toxic contaminants. A recent modification of the swirl concentrator has resulted in a device capable of removing fines. The so-called "teacup solids classifier" creates free and forced vortex fields to handle fines and floatable solids.82

A helical bend concentrator works on principles similar to the swirl concentrator. The helical bend, however, is simply a spiral-shaped conduit placed in the sewer line, so removal by centrifugal force is imparted to the stormwater flow.

Table 5. Evaluation of Runoff Control Methods for Contaminant Types

CONTAMINANTS	TREATMENT/REMOVAL METHODS	
	Effective	Ineffective
Suspended Solids	Erosion Control Vacuum Sweeping Grassy Areas Wetlands Recharge Basins Sediment Basins Swirl Concentrators Microstrainers Dissolved Air Flotation High-Rate Filtration	Detention Basins Broom Sweeping
Bacteria	Disinfection High-Rate Filtration Recharge Basins (good for pathogens, questionable for viruses)	Detention Basins Sediment Basins Swirl Concentrators
Nutrients	Vacuum Sweeping Wetlands Reduced Application of Fertilizers	Broom Sweeping Recharge Basins Detention Basins Sediment Basins
Heavy Metals	Vacuum Sweeping Grassy Areas Recharge Basins Sediment Basins	Broom Sweeping
Salt	Reduced Road Salting Roofed Salt Storage Sheds Snow Berms	Recharge Basins Grassy Areas Porous Pavement Street Sweeping Salt Evaporation Basins
Hydrocarbons a) Oil & Gease	Wetlands Oil Traps with Sorbents and Maintenance Coalescing Filters	Oil Traps without Sorbents or Maintenance Most other methods
b) Chlorinated Hydrocarbons (PCBs, solvents, pesticides)	Reduced or discontinued use Air Stripping	Most other methods

Table 6. Removal Efficiencies of Runoff Control Methods

	CONTAMINANTS (Removal Efficiencies - %)					
CONTROL METHOD	SUSPENDED SOLIDS	ORGANIC WASTES	NUTRIENTS	HEAVY METALS	OIL	OTHER
Street Sweeping (Broom)	20	30	10	28-45		
	20	20-40		10-35		
	50	25-40		38-51		
Street Sweeping (Vacuum)	90	67	85	45-62		
	93			83-98		
Catch Basin Cleaning	32	6				
	56	43				
Detention Basins	25	25		40-70	70	
Sediment Basins	25-50	20-40	20	40-50	70	
	30-70	25-40	38			
	60-90	30				
Recharge Basins	100	92		30-60	good	100-
				90		(bacteria)
Grass Strips	90	80		60-90		
Wetlands	80-90	good	78			
	94					
Microstrainers	25-90	10-70				
Dissolved Air Flotation	40-70	40-60				
Swirl Concentrator	20-70	0-45				
Teacup Solids Classifier	90	40				
High-Rate Filtration	40-90	15-80	30-80			

SOURCE: (research studies listed in Bibliography)

Table 7. Estimated Costs for Runoff Control Methods

CONTROL METHOD	CONSTRUCTION COSTS		OPERATION/MAINTENANCE COST	
Street Sweeping (Rotary Broom)			$ 3-13/curb mile	(a)
			6-23/curb mile	(b)
			0.75/acre	(a)
Catch Basin Cleaning			$ 6-10/basin	(b)
Detention Basins/ Recharge Basins	$ 400-1,000,000	(b)	$ 2750/year	(b)
			7300/year	(c)
Recharge Trenches with Perforated Pipe	$ 2500/acre drained	(d)		
Porous Pavement	$ 8-10/square yard	(b)		
Grass Strips	$ 2400-3600/acre	(b)	$ 50-100/year/acre	(b)
Sediment Basins	$ 10,000-50,000/mgd*	(e)	$ 0.02/gallon	(f)
	568,000/25mgd	(a)		
	1,900,000/25mgd	(f)		
Salt Evaporation Basins	$ 1000-2000/basin	(g)		
Snow Berms	$ 750,000/curb mile	(h)		
Microstrainers	$ 5000-12,000/mgd	(e)	$ 0.22/1000 gallons	(c)
	13,000/mgd	(c)	0.69/1000 gallons	(f)
	323,000	(f)		
Dissolved Air Flotation	$ 40,000/mgd	(e)	$ 0.06/1000 gallons	(f)
	76,000/mgd	(a)		
	842,000	(f)		
	6500/acre	(e)		
Swirl Concentrator	$ 2000-3000/mgd	(e)		
	200,000-300,000	(b)		
Disinfection	$ 1500/mgd	(e)		

*mgd = million gallons per day flow capacity

SOURCES: (a) U.S. Army Corps of Engineers, Eastern Massachusetts Metropolitan Area: Urban Stormwater Management, Vol. 8, 1975.
(b) Massachusetts Department of Environmental Quality Engineering (DEQE), Upper Mystic Lake Watershed Urban Runoff Project, 1982.
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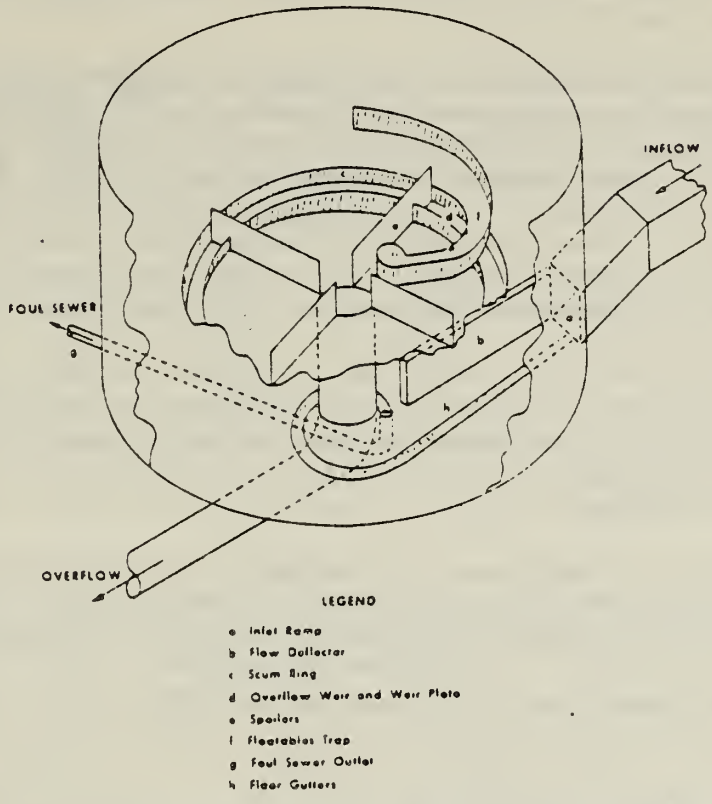

Figure 26. Swirl Concentrator. Source: U.S. Environmental Protection Agency

Conclusions

This report has tried to show how and why local officials should incorporate concerns about runoff quality and aquifer recharge into drainage designs. Stormwater increases in volume and velocity and decreases in quality as it flows over impervious surfaces (roof, streets, etc.) associated with developed areas. Runoff is a major source of water contamination in certain areas. As runoff flows over developed areas it picks up potential pollutants, such as suspended solids, salt, oil, heavy metals and bacteria.

Many sources of these contaminants are transportation-related. Petroleum products (fuels and engine oils) and heavy metals often originate from vehicles. Deicing salt is applied on roadways for motorist safety. Breakdown of road surfaces contribute suspended solids. Other major sources include construction and lawn maintenance.

Presently, most stormwater is collected in conventional closed drainage systems - catch basins and underground drains discharging into surface waters. While this method may solve flooding and erosion problems in an area, it may simultaneously increase threats to water quality by concentrating contaminants. Closed drainage also reduces aquifer recharge when runoff is shunted directly to surface waters. Closed drainage can be modified, however, to accommodate these concerns. The large volume of runoff collected by drains can make the use of treatment devices installed in the system more cost-effective.

Contaminants in runoff pose differing threats to receiving waters. Dissolved contaminants are harder to remove from the environment. Heavy metals are very persistent. Groundwater is particularly vulnerable to salt and nutrients. Small ponds in urban areas are generally susceptible to pollution due to lack of flushing.

The first flush effect is well-documented. This effect refers to the tendency for contaminant levels in runoff to be highest during early stages of a storm. This effect supports the use of storage of stormwater so that it can later be released slowly. As another consequence of the first flush phenomenon, treatment of only the initial volumes of runoff can be considered cost-effective.

There is no one drainage design to solve all runoff problems. A proper mix of solutions, however, can satisfy the four main concerns: flooding, erosion, water quality and groundwater recharge. Individual site conditions, type and use of receiving waters and costs will determine the most appropriate design. It is often difficult to compare costs of drainage designs because varying capacities determine their costs. Maintenance costs may exceed construction costs. Some designs are cost-effective for some contaminants, but not others.

Although more research is needed, infiltration of runoff through soils seems a cost-effective and efficient means of removing many types of contaminants, except salt and nutrients. Aquifer replenishment is accomplished simultaneously by this method. Infiltration can be designed to fit available land space, either in the shape of basins, trenches or wells.

It should be emphasized that a function of drainage design is not to purify stormwater for the sake of having clean stormwater; rather, by cleaning runoff before it enters receiving waters, society is spared the greater expense needed to rehabilitate its ponds for fishing, its bays for swimming and its aquifers for drinking.

Recommendations

1. Include stormwater quality and aquifer recharge concerns in all local review of proposed urban developments. Presume that runoff will increase and stormwater quality will decline when impervious surfaces are added unless the development proponent can present evidence to the contrary, such as by proposing mitigation measures.

2. Try to think about drainage patterns not only as they function on the site, but also as a small component of a larger watershed. There is always some place farther downstream that will receive the drainage discharge.

3. Determine which water resources (aquifer, ponds, streams, coastal waters) are of greatest concern in an area and determine runoff control measures best suited to protect those waters. Remember that all groundwater and surface waters within the same basin are hydrologically connected.

4. Recognize that each control method has a range of efficiencies for removing different pollutants and no one treatment can remove them all. Several different devices or practices may need to be combined for full protection.

5. Recognize that pollutant source controls (street sweeping, reduced chemical application) are the least expensive and most effective means to prevent stormwater pollution. It is easier to prevent rather than treat contamination.

6. Municipal highway departments should purchase more efficient vacuum street sweepers rather than increasing the frequency of conventional rotary broom sweeping to reduce pollutant loads on pavements. Vacuum sweepers can also be used to clean catch basins.

7. Catch basins should have sediments removed more than once per year. Drop inlets without sumps should be installed except where severe erosion problems are likely to contribute excessive suspended solids or where a sump must be used to create an oil trap catch basin. Leaching-type catch basins are preferred where oil traps are not needed and where aquifer protection from road salt is less crucial.

8. Road deicing salt application should be minimized wherever possible. Special attention should be given to road segments traversing wellfields and reservoir tributaries. Switching to reduced salt to sand ratios (less salt, more sand) in the deicing mix should be encouraged, though sand can cause sedimentation problems in receiving waters. Switching from sodium chloride to calcium chloride should also be encouraged, particularly in areas with sand or gravel soils, which easily transmit both sodium and chloride into aquifers. While calcium chloride is more expensive, it also works faster and requires smaller, less frequent applications.

9. Proceed with salt storage construction, including those for town stockpiles. Coastal towns might consider locating salt stockpiles near the shore. Locate new stockpiles outside of water supply areas.

10. Practice erosion control at development sites to prevent sediment loads in runoff. Consider making temporary sediment basins into permanent drainage features.

11. Town boards should cooperate to ensure that development review encourages retaining stormwater on-site as much as possible. Methods to promote recharge are most effective for residential areas. Where lot sizes are small in proposed subdivision, land should be set aside for recharge basins. Gravel driveways or porous pavements are good for flat, low-traffic areas associated with subdivisions.

12. Parking lots should use porous pavement, which is proven to retain its structural integrity even in harsh winter climates. Only the normal operating capacity of the parking lot should be paved; outlying portions of the lot should be graded and covered with pervious materal.

13. Sidewalks and driveways should be installed using porous pavements. Concrete lattice is also aesthetically pleasing as a sidewalk surface.

14. Homeowners and golf course managers who compact their lawns by rolling should combine rolling with aeration, which will aid infiltration and lawn health.

15. Oil traps in catch basins should be installed only when combined with the use of sorbent pads. Sorbents should be removed and replaced on a regular schedule as oil buildup requires, but in no case longer than half-year intervals. Towns should receive written verification that the traps are being serviced.

16. The Massachusetts Division of Hazardous Waste should establish a policy to allow municipalities to remove and store small amounts of oiled sorbents from public catch basins, as long as the municipality arranges to have a licensed contractor transport the collected sorbents for final disposal.

17. Snow berms should be seriously considered for new highways where salting cannot be reduced, particularly near critical water supply areas.

18. Conventional closed storm drains can be installed with perforated pipe. This pipe will promote infiltration and reduce the volume of stormwater finally discharged from the closed system.

19. Grassy areas or other vegetation should be planted wherever possible, particularly around the edge of impervious surfaces, such as parking lots and roads. Grass functions aesthetically as well as a filter for runoff contaminants. Surface swales should be lined with grass wherever possible, instead of impervious materials, such as concrete.

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APPENDICES

APPENDIX A

Formulae to Estimate Peak Runoff Flows

Hydrologic calculations are commonly used to estimate peak flows for various intensity storms. The design of flood control devices, drains, storm sewers, and culverts is based on a peak flow for a specified storm, usually the 100, 50, 25, or 10 year storm. Storm intensity is based on historical records of the U.S. Weather Bureau. "Year storm" relates to the probability of a storm of a certain intensity occurring. A "50 year storm" means that there is a 2% chance that a rainfall of a specified intensity for a specified time will occur. If a "50 year storm" occurs today, there is no assurance that the same intensity storm will not occur tomorrow -- there is still a chance of the same intensity storm occurring.

Two common methods for calculating peak flows are the Modified Soil Cover Complex Mehtod (MoSoCoCo) and the Rational Method.

The MoSoCoCo Method, developed by the U.S. Soil Conservation Service, is based on studies of actual flow records of drainage basins scattered throughout the U.S. the method takes into account variations in site conditions, approximates real-world conditions, and provides a credible estimate of peak flows.

The MoSoCoCo Method uses soils and vegetation maps and a series of charts to determine peak flows. For a detailed and relatively simple, step-by-step, explanation of this method, read Estimating Runoff -- The Modified Soil Cover Complex Method, or Guidelines for Soil and Water Conservation in Urbanizing Areas of Massachusetts, both by the USDA Soil Conservation Service. They are available from regional SCS offices. The method has recently been updated to deal with the special problem of increased flow from urban development. Refer to Urban Hydrology for Small Watersheds, Technical Release No. 55 by SCS. This publication will help answer the question: If "x" amount of water is coming into a site, and only "y" amount is desired to go off the site, how much must be stored on the site?

The MoSoCoCo Method has several advantages. First, if used correctly, it requires a good evaluation of soils, vegetation and slope. This means that the engineer must really learn the site before final design. Other advantages include:

1) fine adjustments for slope,
2) adjustments for wetlands and ponding,
3) adjustments for watershed shape,
4) corrections for percentage of impervious area,
5) special corrections for any proposed channel modification,
6) it allows the volume of runoff over the total time of the storm to be computed, so that the amount of on-site storage which is required to prevent downstream flooding can be computed. In other words, the amount of storage needed to maintain the pre-development rate of runoff, or other acceptable rate, can be computed.

There are some disadvantages, too. They include:

1) soils maps may not be available,
2) generalized soils maps for the area are usually too in-exact for specific site applications,
3) the Massachusetts Department of Environmental Quality Engineering does not generally use this method,
4) other town departments may use the Rational Method,
5) this method does not deal with snowmelt.

The Rational Method may give different results from the MoSoCoCo Method. This should not discourage use of the MoSoCoCo Method by users. It will allow an objective cross-check against the assumptions made in Rational Method calculations.

The Rational Method uses the following formula for determining peak flows: Q = CIA, where

Q = Peak flow in cubic feet per second,

C = Runoff coefficient,

I = Rainfall Intensity in inches per hour,

A = Area of Drainage in Acres.

If used for smaller (less than five acres) man-made areas, this method can give relatively accurate estimates fo the peak rate of runoff. However, for larger drainage areas, the Rational Method gives less accurate results because it cannot adjust to the geater complexity of hydrologic conditions.

Town agencies need to be particularly cautious when reviewing an application which uses the Rational Method. It must be correctly applied, which means that the inputs for each variable must be very carefully selected to reflect actual conditions, existing and proposed.

Runoff Coefficients

Description of Area	Runoff Coefficients
Business	
Downtown	0.70 to 0.95
Neighborhoods	0.50 to 0.70
Residential	
Single Family	0.30 to 0.50
Multi-units, detached	0.40 to 0.60
Multi-units, attached	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Railroad yard	0.20 to 0.35
Unimproved	0.10 to 0.30

Character of Surface	Runoff Coefficients
Pavement	
Asphalt or Concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.70 to 0.95
Lawns, sandy soil	
Flat, 2 percent slope	0.05 to 0.10
Average, 2 to 7 percent slope	0.10 to 0.15
Steep, 7 percent or more slope	0.15 to 0.20
Lawns, heavy soil	
Flat, 2 percent slope	0.13 to 0.17
Average, 2 to 7 percent slope	0.18 to 0.22
Steep, 7 percent or more slope	0.25 to 0.35

The coefficients in these two tabulations are only applicable for storms of five to ten year return frequencies, and were originally developed when many streets were uncurbed and drainage was conveyed in roadside swales.

For recurrence intervals longer than ten years, the indicated runoff coefficients should be increased assuming that nearly all of the rainfall in excess of that expected from the ten year recurrence interval rainfall will become runoff and should be accommodated by an increased runoff coefficient.

The runoff coefficients indicated for different soil conditions reflect runoff behavior shortly after initial construction. With the passage of time, the runoff behavior of sandy soil areas will tend to approach that of heavy soil areas. If the designer's interest is long-term, the reduced response indicated for sandy soil areas should be disregarded.

SOURCE: A Guide to Understanding and Administering the Massachusetts Wetlands Protection Act, Massachusetts Audubon Society, 1977.

APPENDIX B

Massachusetts Water Pollutant Discharge Permit Program

In 1983, the Massachusetts Department of Environmental Quality Engineering's Division of Water Pollution Control (DWPC) issued new regulations to control discharges into ground and surface waters. An important feature of the rules covers stormwater drainage systems. DWPC requires a permit for most systems that discharge runoff into surface waters (ponds, streams, wetlands, coastal waters) or could contaminate ground water by injection or leaching.

The new regulations (314 CMR 1.00.00) give DWPC wide discretion in examining the contamination risk posed by any particular stormwater drainage system. While systems known to discharge polluted runoff (such as those serving industrial plants) are specifically required to obtain permits, the language of the regulations is broad enough to allow DWPC to rule on any other drain. The regulations apply to privately-operated as well as closed drainage systems. Open drainage (swales, basins, trenches) as well as closed drainage systems (catch basins, pipes, outfalls) are subject to permits. Storm drains combined with or leading into municipal sewer pipes are exempt.

DWPC's Surface Water Discharge Permit Program (314 CMR 3.00) represents the state's adoption of the National Pollutant Discharge Elimination System (NPDES), previously administered in Massachusetts by the federal Environmental Protection Agency. The Ground Water Discharge Permit Program(314 CMR 5.00) is new for DWPC and is wide in its scope. Both permit programs require that drainage systems will not discharge contaminants that will cause the receiving water to become polluted or to exceed the water quality standards adopted by Massachusetts.

The new regulations' effect on the cities and towns will depend on their enforcement. Clearly, every single runoff conveyance cannot be evaluated for a permit by DWPC. It is likely the agency will target larger drainage systems, drains collecting industral runoff, systems known to cause pollution problems, and discharges in particularly sensitive areas, such as public water supply areas, for initial enforcement. Cities and towns should expect some increased paperwork for permits for their own municipal drainage systems in the targeted categories. Costs may rise if a community is required to upgrade the quality of its stormwater discharge in an area to meet permit standards.

But communities will also benefit from the new regulations. Municipal officials can notify DWPC of suspected problem drains maintained privately, or, in fact those operated by the state. Towns concerned with road salting practices by the state on roads through critical watersheds can ask DWPC to rule on permits for road drainage in such areas. Local Conservation Commission powers to protect water quality near wetlands can be supplemented with the new state permit authority.